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DEPARTMENT OF NATURAL RESOURCES

IRON RESOURCES

OF

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DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO

STATE OF CALIFORNIA
EARL WARREN, Governor
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO
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IRON RESOURCES of CALIFORNIA

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LETTER OF TRANSMITTAL

To His Excellency, The Honorable Earl Warren
Governor of the State of California

Dear Sir: I have the honor to transmit herewith Bulletin 129, *Iron Resources of California*, prepared under the direction of the Chief of the Division of Mines, Olaf P. Jenkins. This bulletin contains sixteen individual articles contributed by various authorities on the geology and iron-ore resources of the state. As these individual reports were finished they were made available as preprints to the public. Now that all the chapters (Parts A to P, inclusive) have been completed, they have been assembled into one bulletin as a comprehensive and authoritative treatise.

Never before has such a complete bulletin been issued covering in detail descriptive matter concerning all of the known iron-ore deposits of importance in California. During World War II the United States Department of the Interior, through the efforts of its two agencies the Geological Survey and the Bureau of Mines, undertook concurrent cooperative investigations of the California iron resources. The results of this program of work have been released for publication by the State Division of Mines whose Chief has assembled them under one cover, adding pertinent information and coordinated reviews.

Respectfully submitted,

Warren T. Hannum, Director
Department of Natural Resources

February 17, 1948

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PREFACE

Since the earliest days of settling the West, the problem of supplying the new western civilization with iron and steel from local sources has been uppermost in the minds of western industry. Various reports on the subject have appeared from time to time, but no complete assemblage of detailed information as regards the iron-ore resources of California has ever before been published. Results of investigations by the United States Geological Survey and the Bureau of Mines, made during the period of World War II, are now released for publication by the State Division of Mines. These reports, prepared as separate articles, have appeared from time to time in the state series as parts of Bulletin 129. In addition to the contributions (15 in number) by Federal authorities, a report on titaniferous iron ores of the San Gabriel Mountains, by Gordon B. Oakeshott, has been included. All 16 parts (A to P) are now assembled in bound form as Bulletin 129.

To get a general picture of the results of all investigations by the Federal Geological Survey, the reader is referred to Part N, pages 207-229, *Summary of the Iron-Ore Situation in California,* by Ernest F. Burchard. Following this report, Part O, pages 231-241, *Summary of Investigations of the Iron-Ore Deposits of California,* by A. C. Johnson and Spangler Ricker, indicates the work done by the Federal Bureau of Mines.

A brief review of the iron industry of California as it appears today, indicating the various new minerals, besides iron ore, which are used in this industry, is given in the following paragraphs.*

The iron resources of California have long been recognized as potentially capable of yielding high-grade ores in quantities large enough to support a West Coast steel industry. Previous to World War II, however, production was limited to very small amounts of ore consumed in an early pig-iron industry and, in later years, to somewhat larger tonnages used as ship ballast and in the manufacture of high-iron cements.

During World War II, attention was focused on the strategic importance of western iron deposits and two federal agencies of the Department of the Interior, the Geological Survey and Bureau of Mines, undertook concurrent, cooperative investigations of California iron resources. The results of the program, which included studies of the occurrences believed to be of greatest conomic importance, form the bulk of this bulletin. Actually, more than 100 iron deposits, occurring in 31 of the state's 58 counties, are known; but the future production of iron from California sources will undoubtedly center about 13 principal localities herein described.

Approximately three-fourths of California's known iron resources are contained in geologically similar deposits at nine localities in the desert region of the southeastern portion of the state. Of this group, the Eagle Mountains deposits, about 40 miles east of Indio, Riverside County, are the southernmost, and the deposits of the Kingston Range, San Bernardino County, about 30 miles east of the southern end of Death Valley, are the northernmost. Also included are the Iron Mountain (Lava Bed district), Iron Mountain and Iron King (Silver Lake

* Prepared by Lauren A. Wright, Associate Geologist, California State Division of Mines.

district), Old Dad, Cave Canyon, Vulcan, Iron Hat and Ship Mountains deposits, all in San Bernardino County.

An iron district area, in which the deposits closely resemble geologically those of Riverside and San Bernardino Counties, but with lower reserves, lies along the canyon of the McCloud River north of Shasta Dam in Shasta County. The nearly adjacent Shasta and California deposits, near the confluence of the McCloud and Pit Rivers, are by far the largest in the area. The Hirz Mountain deposit, about 2 miles to the north, is considerably smaller.

The Sierra Nevada contains two widely separated iron-bearing localities, the Iron Mountain area (Minarets deposit) in northeastern Madera County, and the area near Lake Hawley and Spencer Lakes in Sierra County.

The ilmenite deposits of the western San Gabriel Mountains, Los Angeles County, are not considered potential iron-ore sources, but they do constitute the principal California titanium reserves. As ilmenite is an iron-bearing mineral closely related to magnetite, descriptions of these deposits are included here.

The major iron deposits of Riverside, San Bernardino and Shasta Counties are of the so-called contact-metamorphic type in which the mineralization is related to a nearby granitic intrusive and has replaced portions of susceptible sedimentary carbonate beds. They are, therefore, distinctive from the principal iron ores of the United States as represented by the residual deposits of the Lake Superior region, and the sedimentary Clinton ores which extend from New York to Alabama. Magnetite is the chief component of these California ores, but hematite is also characteristic and may locally be the more abundant. Limonite occurs in smaller amounts.

The Minarets deposit and the deposits near Lake Hawley and Spencer Lakes differ from the typical contact metamorphic bodies in that they appear to be replacements of meta-andesite and of clastic sediments, tuffs and lamprophyre dikes, respectively. In these, magnetite is the only important iron mineral. No sedimentary iron deposits of economic importance have been reported in California.

The iron reserves of California are estimated at between 100 million and 150 million long tons. More than half of this figure, however, represents material that is sub-marginal under current economic and technologic conditions. Deposits in the Eagle Mountains account for at least one-third of the total reserves; none of the other known California deposits is of comparable size nor is any other single deposit currently capable of supporting a modern steel mill through an amortization period. Several deposits, however, are potentially capable of supplementing domestic or imported ores or, for limited periods, of supporting plants similar to that of the Kaiser Company at Fontana. Deposits of this class include those at Iron Mountain (Lava Bed district), and the Iron Mountain and Iron King (Silver Lake district), Cave Canyon, Vulcan,[1] Beck (Kingston Range), Shasta and California deposits. As indicated or suggested by descriptions in this bulletin, each of these deposits contains more than one million tons of mineable high-grade ore. Development of these properties will be controlled largely by transpor-

[1] Since Dec. 1, 1942, the Vulcan mine has supplied more than $2\frac{1}{2}$ million tons of iron ore to Kaiser Company's Fontana plant. Though the mine was shut down in July 1946, the deposit is not depleted.

tation costs. The Minarets deposit, though of comparable size, is probably too inaccessible to be currently considered in this group.

The remaining deposits, including those at the Old Dad, Iron Hat, Ship Mountains, Hirz Mountain, and Lake Hawley and Spencer Lakes localities, are relatively small.

Large-scale exploitation of the California deposits began in 1942 concurrently with the construction of the Kaiser Company's Fontana steel plant. Consequently iron ore mined in the state rose from a yearly average of 27,304 tons in 1940 and 1941 to 905,981 tons in 1943. Subsequent developments in the use of California ore for steel production have centered wholly about the Fontana operation.[2]

During 1942, 1943 and 1944 the Fontana plant was supplied principally by ore from the Vulcan mine in San Bernardino County.[3] The sulphur content of this ore, however, increased with depth, and since January 1, 1945 the plant has used a blended material of approximately equal amounts of Vulcan ore and a low-sulphur ore obtained from the Utah Construction Company mine, Iron County, Utah. The high sulphur content and increased mining costs forced a cessation of the Vulcan operation in July 1947 after a total of 2,643,000 tons of blast furnace grade ore had been removed.

The future economy of the Fontana plant is to be built upon production from the Kaiser-owned Eagle Mountain mine, Riverside County.[4] The operational facilities of this mine, scheduled for completion by April 30, 1948, will handle a daily ore production of about 3,500 tons. This supply, according to present plans, will be supplemented by a very small production of Utah ore.

In addition to iron ore, other materials required at the Fontana plant include limestone, manganese, and coke for the blast furnace operation and raw and burned limestone, raw and burned dolomite, fluorspar, and runner clay for use in the open hearth furnaces.

A monthly requirement of 2,800 tons of limestone for blast furnace flux is currently obtained from the California Portland Cement Company at Colton. No other future source is anticipated.

Manganese, consumed at a monthly rate of 600 tons, was imported from Mexico during the war. In December 1947 1½ years reserve of plus 40 percent ore remained in stockpiles, but the future sources were undetermined.

Approximately 39,000 tons of high volatile coal and 4,000 tons of low volatile coal are consumed monthly in the production of coke at Fontana. The high volatile coal is produced at Sunnyside, Utah, from a property owned by the Utah Fuel Company and leased by the Kaiser Company. The Kaiser Company also has applied for permission to produce from Government-owned coal lands in the Sunnyside area. The low volatile coals are obtained from independent producers in the McAllister field of Oklahoma.

During the first 3 years of the processing of Vulcan ore a clay flux from the Alberhill district, Riverside County, was used in blast

[2] Data pertinent to the Fontana plant and to mining operations of Kaiser Company, Inc. have been kindly supplied by Mr. Kenneth Powell, Superintendent of Raw Materials. The data are contained chiefly in a mimeographed copy of an address by Mr. Powell entitled *Raw Materials for Kaiser Steel*, delivered before the Mining Section of the Los Angeles Chamber of Commerce, April 23, 1947. This information has since been orally supplemented by Mr. Powell.

[3] See Part F of this bulletin.

[4] See Part A of this bulletin.

furnace operation. The necessity of flux clays was eliminated, however, by the introduction of low-sulphur ore and by improved furnace technique. No clay will be needed in processing Eagle Mountain ores.

Raw limestone is consumed in the Fontana open hearth furnaces at the rate of 5,000 tons monthly. Current sources are the plants of the Riverside Cement Company at Oro Grande, Riverside County, and the U. S. Lime Products Corporation at Sloan, Nevada. The latter producer also furnishes the entire monthly requirement of 1,350 tons of burned limestone in the form of pebble lime.

Raw dolomite, approximately 900 tons of which are consumed each month, was formerly supplied by the Kaiser Company's Permanente Metals quarry near Salinas, Monterey County. This material is currently purchased from the U. S. Lime Products Company, Sloan, Nevada. The Salinas operation, however, still supplies the 875-ton monthly requirement of burned dolomite.

Approximately 225 tons of fluorspar are required each month. The Baxter mine near Fallon, Nevada, is the present source. The Staats mine near Lund, Utah, also formerly contributed fluorspar and a small production has been obtained from the Crowell mine near Beatty, Nevada.

Open hearth runner clay, of which 100 to 150 tons per month are consumed, is furnished by the Alberhill Coal and Clay Company, Alberhill, Riverside County.

All ferroalloys consumed at Fontana, with the exception of ferrosilicon, are purchased in the east. Ferrosilicon is obtained from the Kaiser Company's Permanente Metals plant, San Jose, California.

The production of iron-ore for ship ballast and the manufacture of high-iron cement is very small compared with the Fontana plant consumption. During World War II, ballast for Navy ships was produced from the Shasta and California deposits in Shasta County. The Cave Canyon deposits in San Bernardino County for a number of years have been the chief source of ore for high-iron cement. Small amounts of magnetite sand for use as heavy aggregate material have been intermittently produced from beach sands at Aptos, Santa Cruz County, and Hermosa Beach, Los Angeles County, and from stream beds in Sand Canyon, Los Angeles County.

OLAF P. JENKINS
Chief, Division of Mines

San Francisco
February 17, 1948

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

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GEOLOGIC BRANCH
FERRY BUILDING, SAN FRANCISCO

OLAF P. JENKINS
Chief Geologist

SAN FRANCISCO] BULLETIN No. 129—PART A [JUNE 1945

Iron Resources of California

Bulletin No. 129

PART A

Iron-Ore Deposits in the Eastern Part of the Eagle Mountains Riverside County, California

By JARVIS B. HADLEY
Geological Survey, U. S. Department of the Interior

Issued by the
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DIVISION OF MINES
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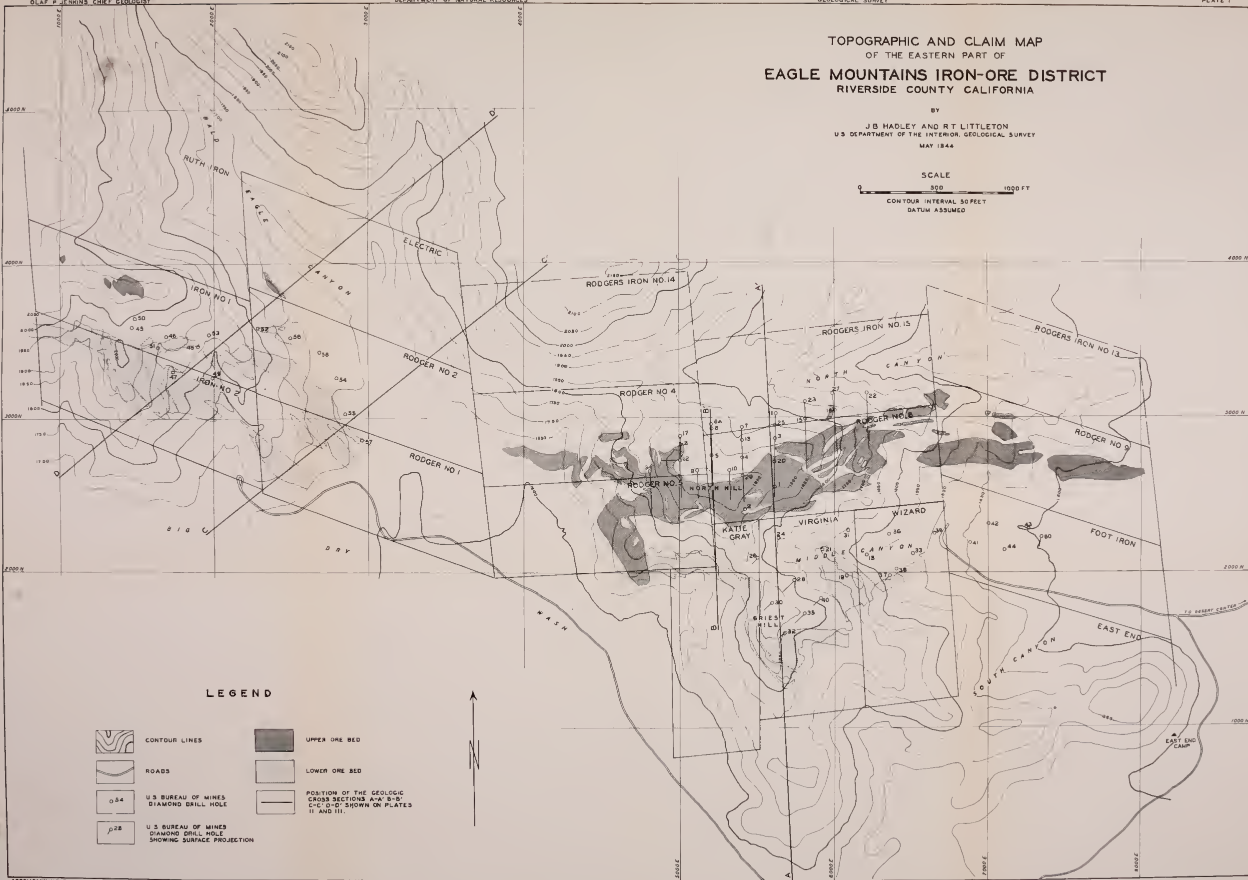
STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

U S DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE I



IRON ORE DEPOSITS IN THE EASTERN PART OF THE EAGLE MOUNTAINS, RIVERSIDE COUNTY, CALIFORNIA *

By Jarvis B. Hadley **

United States Department of the Interior, Geological Survey and Bureau of Mines (Project 902)

OUTLINE OF REPORT

ABSTRACT

In 1941-42 iron-ore deposits in the northeast part of the Eagle Mountains, Riverside County, California, were examined and mapped in detail by the Geological Survey and explored by the Bureau of Mines, both of the United States Department of the Interior, as part of a general investigation of raw material resources for western steel production.

The iron ore is associated with dolomite, quartzite, and lime-silicate rocks of igneous-metamorphic origin, which have been invaded by quartz monzonite. Two beds, one 80 feet thick, the other 30 to 300 feet thick, are ore-bearing for more than 8,000 feet along their strike. The stratified rocks dip 20° to 60° and are broken by normal faults.

Magnetite and hard red hematite mixed with various amounts of tremolite, serpentine, talc, and micas constitute the ore. Its specific gravity ranges from 3.5 for granular ore estimated to contain 50 percent iron oxide to 4.5 for massive hematite and to nearly 5.0 for magnetite. Pyrite is widely disseminated in fresh ore in the lower part of the deposits, where it averages about 3 percent, equivalent to 1.5 percent sulfur. It has generally been removed by oxidation within 150 or 250 feet of the surface. One-half to three percent gypsum, equivalent to 0.1 to 0.6 percent sulfur, is generally found in ore in the oxidized zone.

The iron content of the ore ranges from 30 percent to 65 percent. The average ore contains 50 percent iron, 11 percent silica, 5 percent magnesia, 2.5 percent lime, 2.5 percent alumina, and 0.085 percent phosphorus. Sulfur generally averages less than 0.2 percent in oxidized ore (0.4 percent in one deposit) and 1.5 percent in fresh ore. Phosphorus, presumably in apatite, is associated with gangue minerals rather than with ore minerals.

Five major orebodies containing 2 to 16 million tons each and one smaller body have been sampled by trenching and diamond drilling. They are 600 to 1500 feet long, 70 to 300 feet thick, and extend 200 to 750 feet down dip. Measurable ore in these bodies totals 28 million long tons containing more than 30 percent iron, with an average grade of 50 percent iron and 0.4 percent sulfur. In addition about 15 million tons of inferred ore estimated to contain 45 to 55 percent iron is believed to exist in smaller or less accessible bodies within the area investigated.

About 75 percent, or 20 million tons, of the measurable ore could probably be mined from surface pits, and about 30 percent of this amount, or 7 million tons, is estimated to be shipping ore containing more than 50 percent iron and less than 0.2 percent sulfur.

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* Published by permission of the Director, Geological Survey, Department of the Interior. Manuscript prepared August 1942; submitted for publication August 23, 1944.

** Geologist, Geological Survey, U. S. Department of the Interior.

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** Geologist, Geological Survey, U. S. Department of the Interior.

INTRODUCTION

Iron-ore deposits in a district 6 miles long and 1½ to 2 miles wide in the northeast part of the Eagle Mountains, Riverside County, California, were described by E. C. Harder (12). The deposits are covered by more than 100 patented claims, most of which are now held by the Southern Pacific Company of San Francisco and the remainder by the Iron Queen Mining Company of Los Angeles. The present geologic investigation of a part of this district was conducted in the fall of 1941 and the spring of 1942 by the Geological Survey, United States Department of the Interior, in cooperation with an extensive program of trenching and diamond drilling by the Bureau of Mines of the Department of the Interior, as part of an investigation of raw material resources for the production of iron and steel in the Western States. (Bureau of Mines Project No. 902.)

The area investigated covers 1½ miles by half a mile at the east end of the iron-ore district, in secs. 34, 35, and 36, T. 3 S., R. 14 E., San Bernardino base and meridian (see fig. 2). The area is 15 miles by paved road from Desert Center, California, a town on U. S. Highway No. 70. The nearest railroad points are Mecca, California, 43 miles distant, on the Union Pacific Railroad, and Rice, California, 52 miles distant, on the Santa Fe Railroad. Blythe and Indio, the nearest sources of most supplies, are each about 60 miles by paved roads from the deposits. The Colorado River aqueduct of the Metropolitan Water District of Southern California passes within 2 miles of the deposits, and the settlement and pump-lift station of Eagle Mountain are 5 miles away.

No commercial production of iron ore has been made from the district, although several hundred prospect shafts and adits have been dug. Gold was formerly mined at the Iron Chief mine in the western part, and lead and zinc were mined at the Black Eagle, or Scott mine, which was abandoned in 1941.

Robert T. Littleton of the Geological Survey, United States Department of the Interior, ably assisted throughout the field work. The writer also wishes to acknowledge with thanks the hospitality of the staff of the Metropolitan Water District at Eagle Mountain, and the cooperation of W. D. McMillan and F. A. Rutledge, engineers in charge for the Bureau of Mines, Interior Department. All assay data used in this report were furnished by the Bureau of Mines.

GEOLOGY

The iron-ore deposits are in contact-metamorphosed sedimentary rocks which have been folded, faulted, invaded by irregular, sill-like bodies of quartz monzonite, and cut by dikes of fine-grained igneous rocks. These rocks are summarized in Table 1 and their distribution is shown on Plate I.

Rocks

Vitreous quartzite and feldspathic quartzite constitute the "vitreous quartzite series" of Harder (12, pp. 30-35). Vitreous quartzite is among the most resistant rocks in the region and forms bluffs of brownish white outcrops. Its maximum exposed thickness is 150 feet, although the base is generally cut out by quartz monzonite. Schistose, feldspathic quartzite is one of the least resistant rocks and forms smooth slopes and

Table 1—Rock units in the eastern part of the Eagle Mountains iron district.

Rock units in order of age	*Lithology*	*Approximate thickness, feet*
Slope wash and alluvium	Coarse sand and gravel, commonly cemented by caliche. Locally contains abundant boulders of iron ore.	0 to 100+
Dike rocks	Syenite porphyry, diabase, granite.	
Quartz monzonite	Coarse-grained and porphyritic quartz monzonite with biotite and hornblende.	
Conglomerate	Metamorphosed limestone conglomerate.	400+
Lime-silicate rocks	Contact-metamorphic rocks composed of mica, actinolite, diopside, feldspar, and quartz.	100
Upper ore bed	Iron ore with lenses composed dominantly of lime-magnesia silicates.	30 to 300
Quartzite	White to dark-gray glassy quartzite; sporadic bodies of iron ore.	200 to 300
Lower ore bed	Iron ore with lenses composed dominantly of lime-magnesia silicates.	40 to 140
Feldspathic quartzite	Coarse- to fine-grained feldspathic quartzite and schist.	50 to 150
Vitreous quartzite	Pure, coarsely recrystallized quartzite.	150+
	Total average thickness of metamorphic rocks	1250

saddles. It is most easily recognized by its tendency to break parallel to bedding into small angular slabs, and by red, yellow, and gray colors in some weathered outcrops. Beds of relatively pure quartzite several feet thick appear locally within the schistose quartzite, and a zone of mica schist or pale-green quartz-feldspar rock a few tens of feet thick commonly lies at the top.

The lower ore bed conformably overlies the feldspathic quartzite and consists of iron ore and related lime-silicate rocks, although to the west it passes into coarsely crystalline dolomite with sporadic iron ore. The ore bed is 50 to 90 feet thick in the eastern part of the area and is as much as 140 feet thick in the western part. The variation in thickness is due in part to interfingering with the overlying beds, a feature especially noticeable northwest of Briest Hill.

The rock immediately above the lower ore bed is dominantly quartzite, which contains more quartz and is less schistose than the feldspathic quartzite and finer-grained than the vitreous quartzite. On Briest Hill the lower part of the quartzite that overlies the lower ore bed is dark gray and distinctively banded with closely-spaced discontinuous layers a half inch or less wide containing disseminated iron oxides and lime-silicate minerals. The upper part is generally white, has a sugary texture, and is closely fractured. West of Bald Eagle Canyon, the quartzite is more massive than elsewhere and much of it resembles the vitreous quartzite. It also contains much light-colored granite and dioritic rock in irregular bodies which have obscure boundaries. Similar vitreous quartzite beds and granitic bodies occur near the top of the quartzite on North Hill. Lenses rich in diopside or tremolite are present locally in the quartzite, and several small bodies of iron ore occur in it.

The upper ore bed, like the lower one, is composed of iron ore and silicates and passes westward into dolomite. The base of the ore bed is commonly marked by a zone 10 or more feet wide consisting of serpentine

and tremolite, or alternating layers of iron ore and greenish feldspathic quartzite.

Stratigraphically above the upper ore bed in the vicinity of North Hill are well-bedded rocks composed of quartz, feldspar, mica, actinolite, and diopside in various proportions. They are so severely folded that an accurate determination of thickness is not possible.

Metamorphosed conglomerate composed of quartz, feldspar, tremolite, and diopside forms the upper parts of the hills north of the orebodies and is the highest known stratigraphic unit, although it is everywhere separated from the lower beds by quartz monzonite.

The metamorphic rocks are cut by quartz monzonite and associated aplite, granite, syenite, and diorite, to which the metamorphism and mineralization are probably related. Coarse-grained and commonly porphyritic quartz monzonite forms interconnected elongate bodies ranging from 100 to more than 1,000 feet in width and from half a mile to several miles in length. At the margins of these bodies many smaller sills and tongues have penetrated the metamorphosed rocks and contain many inclusions of them. The quartz monzonite is partly in contact with ore, but is more commonly separated from it by an irregular zone of lime-silicate rocks. The marginal part of the quartz monzonite commonly differs considerably from the normal rock; such marginal rocks, as seen at the surface and in drill cores, are recognized by coarseness of grain and absence of dark minerals and quartz, or by abundance of biotite or hornblende or both, with or without quartz.

A fine-grained pale-green rock marked by small feldspar phenocrysts and identified in the field as syenite, appears in dikes 1 to 50 feet wide, which are especially abundant in the eastern part of the upper ore bed. One such dike extends more than 3,000 feet from east to west and was found in drill holes as much as 450 feet below the surface. The dikes follow two sets of fractures, one at considerable angles to the bedding and the other nearly parallel to it, giving the dikes irregular and disjointed shapes. The dikes are not mineralized, but locally contain inclusions of ore. Other dikes, largely confined to the Bald Eagle deposits, are dark greenish-gray diabase and are 1 to 20 feet wide. They commonly lie along southwest-dipping faults and are younger than the ore.

Structure

The stratified rocks are on the north limb of a broad anticline which trends west-northwest. They have been further deformed by local folding so that at some places their strike departs widely from the regional trend. The dip generally ranges from 20° N. to nearly vertical but near the quartz monzonite on North Hill the well-bedded rocks above the upper ore bed have been compressed into a series of small folds a few feet across, so that reverse (southward) dips are common. On the west end of North Hill, the upper ore bed is involved in a syncline which plunges 35° to 45° NE. Quartz monzonite, in the trough of this syncline, has deeply embayed the ore bed. (See section B-B′, on Pl. II.)

High-angle normal faults with vertical separations which range from a few feet to more than 300 feet displace the ore beds at many places. They trend north to northwest and dip generally southwestward, though a few are vertical or dip steeply to the east.

Although the larger quartz monzonite bodies follow the strike of the stratified rocks for several miles to the west of the area, they cut

across the beds in many places and are believed to be more or less discordant downward. Drilling in the upper ore bed on North Hill has shown that the quartz monzonite that limits the bed on the north has a steep cross-cutting contact with many offshoots into the bed and the adjacent metamorphic rocks. (See section A-A′, Pl. II.)

ORE DEPOSITS

Origin of the Ore

The great quantity of iron in these deposits is believed to have resulted from the action of the quartz-monzonite magma on calcareous beds in the invaded rocks. The stages in the metamorphism and associated deposition of iron oxides can be indicated here only generally and tentatively pending further mineralogical and chemical study. An earlier thermal phase of metamorphism seems to have formed diopside, actinolite, grossularite, wollastonite, scapolite, and labradorite in impure calcareous rocks containing sufficient silica and alumina, but did not materially change the purer dolomite beds. In a somewhat later hydrothermal phase dolomite was extensively altered, first to tremolite, then to serpentine. Magnetite and pyrite were deposited along with these minerals, not only in the dolomite beds, but also in veins in the adjacent quartzite. Elsewhere the quartzose and feldspathic rocks were sericitized. Sometime after the magnetite was deposited, much of it was altered to pseudomorphous hematite, but it is not known to what extent this alteration resulted from supergene processes.

The possibility has been considered that the magnetite was formed by metamorphism of beds of sedimentary iron. This is believed to be not true for the following reasons: (1) no evidence of iron-bearing beds of sedimentary origin is found in the unaltered dolomite or in other beds of the metamorphosed sediments; (2) the magnetite bodies generally do not occur as beds in the dolomite, nor is stratification well preserved in the iron deposits; (3) metamorphism of iron deposits known to be of sedimentary origin tends to produce hematite rather than magnetite; all of the hematite seen in the Eagle Mountains deposits is pseudomorphous after magnetite or pyrite; (4) the constant association of pyrite with the ore suggests a hypogene origin for the iron.

Character and Grade of Ore

The highest-grade ore is hematite or magnetite with less than 5 percent impurities and contains as much as 65 percent iron. The hematite is generally more abundant than the magnetite but a large part of the ore contains both. Bodies composed wholly or largely of magnetite are lenticular and have a maximum known width of about 40 feet. Their downward extent is illustrated by figure 4. The magnetite occurs in tightly interlocking grains one-fourth inch or less across and at some places has moderate polarity. The hematite is red, hard, and dense. It has resulted from alteration of magnetite and generally contains pseudomorphs and unreplaced remnants of magnetite. The hard hematite ore has a specific gravity of about 4.5, which with increasing amounts of magnetite, approaches 5.0.

Some of the ore is a mixture of granular hematite or magnetite with tremolite, serpentine, talc, mica or chlorite, in which the proportion of

gangue ranges from 5 to 50 percent. The size of the mineral grains ranges from 0.1 millimeter to 2 millimeters, and averages somewhat less than 1 millimeter. Other ore contains gangue minerals in irregular bunches with dimensions ranging from a few inches to a foot. Part of the ore is tremolite and serpentine with minor amounts of irregularly disseminated magnetite or less commonly hematite. The iron content of this ore is generally less than 40 percent; the specific gravity ranges between 3.0 and 3.5.

Veins of silicified magnesite or sepiolite, a few inches to 2 feet wide, commonly follow the bedding and fracture planes in the ore. Seams of oxidized copper minerals are similarly distributed at several places, and suggest the presence of chalcopyrite in the fresh ore.

Bedding has generally been obliterated in the ore deposits, except near the base of the ore beds, but locally bands of granular ore in more massive ore indicate original bedding; large lenses of lime silicates also tend to lie parallel to the bedding in the better ore. At some places ore appears to follow fractures at considerable angles to the bedding.

The ore is jointed and tends to break into irregular blocks ranging from an inch to 3 feet across. There is little tendency for the ore to break in any consistent direction, except at the base of the beds, where it tends to break parallel to the bedding. Much of the ore is cavernous; open spaces several feet long were found in tunnels in the upper ore bed.

Pyrite, the only sulfide observed in the ore, is present chiefly in fresh ore in the lower parts of the deposits. It is unevenly distributed and may amount to as much as 10 percent in a few samples. Exploration has not been sufficient to determine the shape or extent of individual pyritiferous bodies, but the average amount of pyrite in fresh pyritiferous ore ranges from about 3 to 4 percent, equivalent to 1.5 or 2 percent of sulfur. Pyrite occurs in irregular grains 5 millimeters to less than 0.1 millimeter across, in thin tablets 0.5 millimeter by 5 millimeters or less, and in veinlets less than 0.5 millimeter wide and as much as several centimeters long.

According to Bureau of Mines assays, average ore above a 30 percent cut-off contains 50 percent iron, 11 percent silica, 5 percent magnesia, 2.5 percent lime, 2.5 percent alumina, 0.085 percent phosphorus, and 0.4 percent sulfur. Average amounts of silica, magnesia, and lime as determined in composite sludge samples, each representing 40 to 80 feet of drill hole, are shown plotted against iron content in figure 5. Alumina, determined in relatively few samples, ranges between 2.0 and 3.5 percent. The curves for silica, magnesia, and lime are nearly parallel in the range below 50 percent iron and represent approximately the same proportion of these oxides that is found in tremolite. The tendency for the CaO curve to become level at about 2 percent in ore containing 50 percent or more iron is probably due to the presence of gypsum and calcium carbonate.

The amount of phosphorus determined from composite sludge samples ranges from 0.02 percent to 0.20 percent with the exception of two samples with 0.26 and 0.46 percent; equivalent core assays of phosphorus were not made. Assays made for phosphorus on cores from drill holes 1 and 2 (sludges not sampled) yielded an average of about 0.1 percent; but individual 4-foot samples carried as high as 1.1 percent. Phosphorus appears to be associated more abundantly with the gangue

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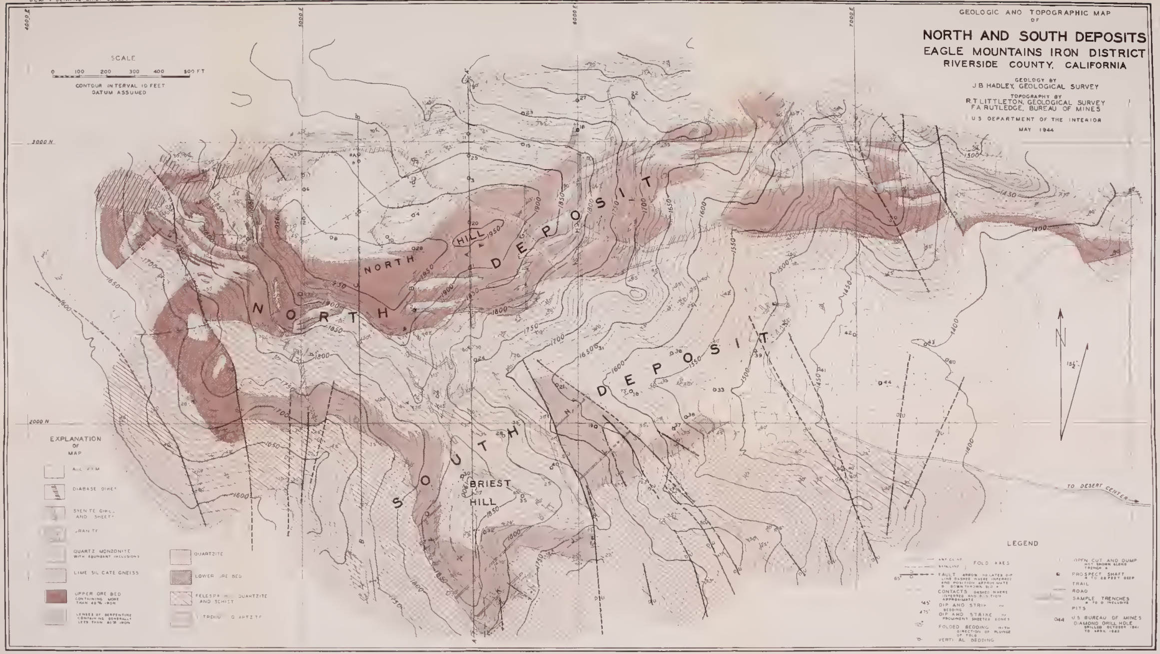
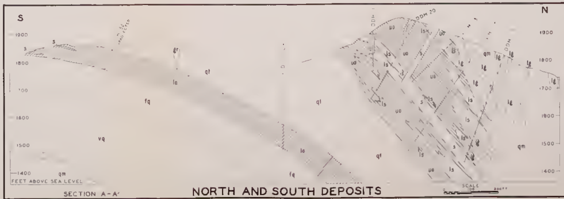
GEOLOGICAL SURVEY

PLATE II



STRUCTURE SECTIONS



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minerals than with the iron oxides, for cores low in iron are proportionally high in phosphorus. Sink-and-float tests made by the Bureau of Mines verify this conclusion. Phosphorus is more abundant in the North orebody than elsewhere, probably because of the proximity of the quartz monzonite.

Other minor substances in the ore, determined from composite sludge samples, include 0.7 percent manganese, 0.12 percent titanium dioxide, TiO_2, 0.10 percent copper, and traces of arsenic, chromium, and nickel. Assays for TiO_2 were obtained from only two sludge samples from the South orebody and the amount is probably higher in the North orebody, because of the proximity of igneous rocks containing considerable sphene.

Changes Due to Oxidation and Weathering

Pyrite has been largely removed by oxidation at most places within 200 feet of the surface, and locally to greater depths, although pyrite was encountered in the oxidized zone in several drill holes and at one place on the surface.

The gangue in the oxidized ore is generally altered to soft, claylike minerals; thus, oxidized granular ore is soft, crumbly, and stained with limonite. At the surface such soft ore may be hardened again by deposition of opaline silica.

Gypsum is irregularly distributed but generally present in the oxidized zone and extends to the lowest depth explored. It fills seams ranging from one-fiftieth of an inch to 1 inch in width, lines cavities, and is disseminated in the ore. The average amount in the oxidized zone varies with different orebodies and ranges from less than 0.5 percent to 3 percent, equivalent to 0.1 to 0.6 percent sulfur.

Abnormally large amounts of gypsum, concentrated in bodies of decomposed gangue minerals, were encountered in some of the trenches. This gypsiferous soil fills cracks in the ore as much as 10 feet below the surface and contaminates the ore with much sulfur. Samples from these trenches contain as much as 5 percent sulfur, equivalent to 26 percent of gypsum.

Figure 6 illustrates changes, with increasing depth, in the iron and sulfur content of ore above 40 percent iron. Ore at or near the surface has been enriched by as much as 5 percent iron as a result of removal of pyrite and leaching of gangue minerals. The sulfur content also abruptly increases at about 250 feet depth, as the deeper holes are chiefly in the unoxidized zone.

Orebodies

Six orebodies were sampled by trenching and drilling. These are the North deposit, the South deposit, which includes three distinct bodies separated by faults, and the Bald Eagle deposit in which two orebodies are separated by a fault. Two-thirds of the ore in the area is in these bodies. Several other bodies, mapped but not sampled, are parts of the upper and lower ore beds which are separated from the principal deposits by faults or by intervening areas of essentially barren material.

North Deposit. The North deposit has been trenched and drilled over a strike-length of 1400 feet. (See Pl. II.) In this distance the orebody is 200 to 300 feet thick and extends down dip more than 350 feet

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at the west end and more than 500 feet at the east end. It is probably cut off by quartz monzonite 400 to 850 feet down dip from the outcrop. (See section A-A′, Pl. II.)

The footwall is fairly uniform, though somewhat warped so that its dip ranges from 30° to 65° N. The hanging wall on the contrary is much complicated by folding and by tongues of quartz monzonite partly enveloped by haloes of lime-silicate rock. A mass of such tongues forms a considerable embayment in the hanging wall in the vicinity of trench C, and in successive sections eastward from trench C the upper part of this embayment appears in drill holes at lower levels as far as trench A. West of trench C the embayment appears to occupy a synclinal trough in the upper part of the ore bed almost as far as trench D. The hanging wall is further complicated, in the west end of the orebody, by tongues of ore projecting into the overlying lime-silicate rocks.

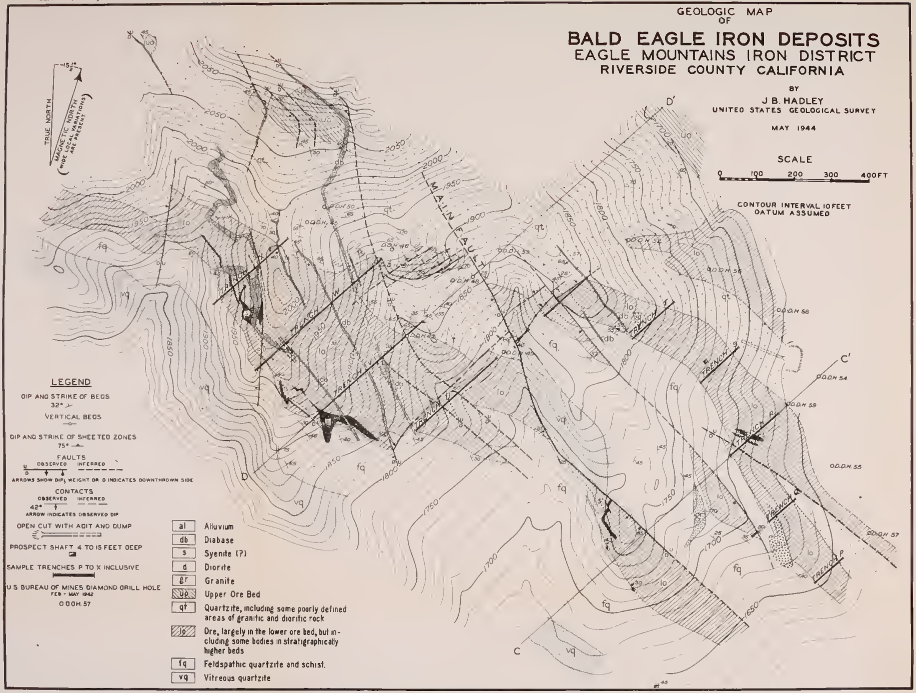
Lenses of gangue, some of them 30 to 40 feet wide and 200 to 300 feet long, occupy a considerable part of the ore bed. (See Pl. II.) The amount of these lenses in different explored sections of the orebody ranges from less than 10 percent in a section along trench D to 40 percent along trench C, the proportion increasing generally down dip and toward the ends of the orebody. The larger lenses could probably be avoided in mining, but it might be difficult to segregate many of the smaller ones. The amount of the smaller lenses in the drilled part of the North deposit is believed to be about 1,000,000 tons.

No key beds were found in the North deposit that would permit correlation from hole to hole or from section to section. The internal structure of the ore was interpreted from the attitude of the base of the ore bed as determined by drilling, from meager observations of poorly preserved bedding at the surface, and on the basis of the lithologic character of the cores modified by assay data. This tends to exaggerate somewhat the continuity of low-grade bodies, but it is the best that could be done under the circumstances.

In the North deposit, the zone of oxidation extends to an average depth of about 200 feet, but tongues of oxidized ore are found at lower levels and pyrite is found locally at higher levels. About 65 percent of the orebody is believed to lie within the oxidized zone. Six or eight percent of the ore in the oxidized zone is estimated to be pyritiferous, and the average sulfur content of all ore in the zone is about 0.4 percent. The distribution of sulfur and pyrite in the oxidized and unoxidized zones is illustrated by figure 8.

South Deposit. The South deposit (Pl. II) has been explored over a strike-length of 2,200 feet. The ore bed is 25 to 90 feet thick and extends in places at least 650 feet down dip from the outcrop. The bed dips northward or northeastward 25° to 30° in the western part and northward 40° to 50° in the eastern part. About 10 percent of the explored part of the deposit consists of lenses of lime-silicate rock and serpentine.

At the east end of the South deposit, the lower ore bed is buried under 70 feet of alluvium. For 500 feet west of the explored area the ore bed, which is 70 to 100 feet thick, is poorly exposed and contains a large proportion of low-grade or barren material. The downward limit of the ore bed in the South deposit is not known. The bed is 40 to 80 feet thick in the lowest drill holes and lies 210 feet stratigraphically



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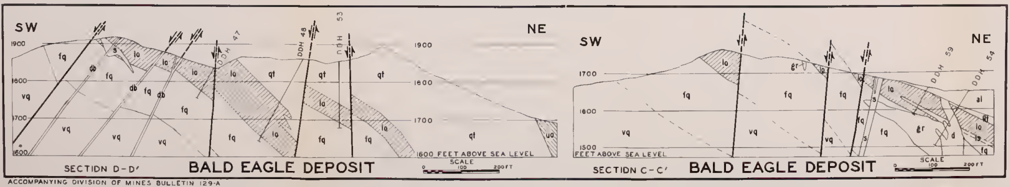

below the base of the upper ore bed at the south end of trench A (Pl. II). The bed probably extends several hundred feet below the drill holes, and possibly 1,000 feet if it is cut off by the same body of quartz monzonite that forms the lower limit of the North deposit.

About 90 percent of the measurable ore in the South deposit lies in the oxidized zone and is essentially free from sulfides. Sulfur in this ore averages 0.13 percent. Pyrite appears only in the lower parts of the deposit, more than 100 feet below the surface and the sulfur content of the unoxidized ore is about 1.4 percent.

The South deposit is broken by two faults into three separate orebodies. The western orebody, about 600 feet by 800 feet, 70 feet thick, contains half of the measurable ore in the deposit. About two-fifths of this ore is covered by quartzite with an average thickness of 70 feet and a maximum thickness of 100 feet. The eastern block contains about 40 percent of the deposit in a tabular body about 1200 by 300 by 60 feet, most of which is covered by 100 feet or more of quartzite and alluvium. The central block, containing less than 10 percent of the deposit, is a wedge-shaped body about 450 by 200 by 60 feet exposed on a dip slope and is partly covered by a remnant of quartzite not more than 10 feet thick.

Bald Eagle Deposit. The Bald Eagle deposit (Pl. III) occupies the same stratigraphic position as the South deposit. It consists of two principal orebodies and several smaller bodies, separated from each other by high-angle faults. The principal fault trends northwest, midway through the deposit, dips 85° SW., and has a maximum throw of about 300 feet.

The ore bed has been explored for 600 feet northwest of this fault, and 1,000 feet to the southeast. The western part is 80 to 140 feet thick and extends down dip at least 600 feet. The well-defined footwall dips about 35° near the surface but steepens down dip to 55°. The hanging wall is irregular and the quartzite in it is erratically folded. One aspect of this irregularity is seen in the prong of ore that extends into the overlying quartzite between trench V and trench W where the ore seems to have followed a set of fractures trending northeast. The ore bed itself has apparently been displaced along similar fractures near the east end of trench U.

The eastern block extends at least 150 to 250 feet down dip. The thickness decreases downward and eastward from 80 to 45 feet, and the average dip decreases eastward from 55° to 40°. At a depth of 170 feet, the eastern block is cut in the vicinity of trenches R and S by diabase dikes and small bodies of diorite, most of which are not exposed at the surface.

Lenses of low-grade or barren rock are erratically distributed, principally in the western block, where they amount to about 15 percent of the orebody. Pyrite is present only in the deeper parts of the western block, most of it more than 200 feet below the surface. About 80 percent of the measurable ore in the deposit is believed to lie in the oxidized zone, and to contain 0.08 percent sulfur. Ore below the oxidized zone contains about 1.5 percent sulfur.

East of the explored area, the ore bed is deeply covered by alluvium; to the west, both grade and accessibility of the ore bed diminish. The downward limit of the ore bed in the Bald Eagle area is not known. The deepest drill holes everywhere indicate a markedly

below the base of the upper ore bed at the south end of trench A (Pl. II). The bed probably extends several hundred feet below the drill holes, and possibly 1,000 feet if it is cut off by the same body of quartz monzonite that forms the lower limit of the North deposit.

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Table 2—Iron-ore reserves, east end, Eagle Mountains district

Based on sample data obtained by U. S. Bureau of Mines

MEASURABLE ORE

	Maximum depth inferred, in feet		Ore containing								Total ore having an Fe content of 30 percent and over							
			30 percent or less Fe		30 to 40 percent Fe		40 to 50 percent Fe		Over 50 percent Fe			Fe	S	P[1]	SiO_2[1]	MgO[1]	CaO[1]	Al_2O_3[1]
	Below surface	Down dip	Millions of long tons	Average percent Fe	Millions of long tons	Average percent Fe	Millions of long tons	Average percent Fe	Millions of long tons	Average percent Fe	Millions of long tons	Average percent						
North deposit	600	600	2.0	23	2.0	34	7.0	46	7.0	56	16	49	[4]0.7	0.124	12.3	4.5	2.5	------
South deposit	300	750	0.1	22	0.5	36	1.6	45	4.8	55	6.9	51	[5]0.20	0.027	11.0	4.5	2.1	2.8
Bald Eagle deposit	450	650	0.1	16	0.2	36	1.6	45	3.3	55	5.1	51	[6]0.36	0.056	12.0	5.8	2.7	2.6
Total measurable ore	600	750	2.2	23	2.7	35	10.2	46	15.1	55	28.0	50	0.40	0.085	[2]12.	[2]4.8	[2]2.5	------
INFERRED ORE[3]																		
Class A:																		
West extension, North deposit	150	150									1.0	52	0.15					
East extension, North deposit	300	200									2.5	50	0.20					
Bald Eagle deposit	100	100									0.5	52	0.10					
Total Class A ore	------	------									4.0	51	0.2					

Class B:						
West extension, South deposit	550	400		2.0	45-50	0.5
West extension, Bald Eagle deposit	350	250		1.5	45-55	0.5
East side Bald Eagle Canyon	250	250		0.5	50-55	0.3
Total Class B ore				4.0	47	0.5
Class C:						
North deposit	750	850		2	45	1.5
South deposit	400	1000		3	45-50	1.5
Bald Eagle deposit	650	1000		2	45-50	1.5
Total Class C ore				7	45-50	1.5
Total inferred ore				15	45-50	
Total reserves				43	49	

[1] From assays of composite sludge samples.
[2] Assays from one hole only.
[3] Grades of iron and sulfur estimated.
[4] 11,000,000 tons oxidized, 0.4 percent S; 5,000,000 tons unoxidized 1.3 percent S.
[5] 6,500,000 tons oxidized, 0.13 percent S; 400,000 tons unoxidized 1.1 percent S.
[6] 4,000,000 tons oxidized, 0.08 percent S; 1,000,000 tons unoxidized 1.5 percent S.

reduced thickness of the ore bed, or an increase in the amount of waste material in it. The nearest quartz-monzonite outcrops in the direction of the dip are 1,000 feet distant; thus the bed may extend several hundred feet below drill holes.

RESERVES

About 43 million long tons of iron ore, containing 30 percent or more of iron, are estimated to be present in the area investigated. Of this 28 million tons contain more than 30 percent of iron in sampled bodies and can be said to be measurable ore; the rest, amounting to 15 million tons, is inferred ore in bodies of various sizes and degrees of accessibility.

Measurable ore is largely within blocks bounded by trenches and drill holes. At some places, ore that extends 20 to 100 feet beyond trenches and drill holes is included where geologic factors indicate there is a small margin of error relative to the accuracy of sampling within the explored blocks. Inferred ore includes ore below drill holes and ore that has not been sampled either by trenching or drilling. It has been divided into three classes depending upon accessibility and the extent of information available:

Class A—Well-exposed with good geologic control; grade judged to be similar to measurable ore but margin of error greater, principally because of lack of precise information as to downward extent.

Class B—Poorly exposed and geologic information less complete than for class A; over-all grade probably less than for measurable ore.

Class C—Below explored orebodies; estimates of grade and quantity subject to considerable error.

Classification of ore according to iron content was made as follows: assays from trenches and drill holes were divided into sections 15 or more feet long, each considered to represent a minable unit with an average iron content falling within one of four classes: below 30 percent, 30 to 40 percent, 40 to 50 percent, and above 50 percent. A very small part of the reserves contain more than 60 percent iron. Most of the assays in each unit fall within the appropriate grade limits, but the iron content of the ore is so variable that some individual assays of 5-foot samples are lower or higher than the average of the unit by as much as 15 percent. The proportions of the different classes of ore as represented in drill holes and trenches were computed by sections in each orebody, the sections then weighted according to their areas and combined to give the grade-percent curves shown in figure 7. The total tonnage of measurable ore in the North, South, and Bald Eagle deposits was calculated separately, at 8.5 cubic feet per long ton. Tonnages of classified ore (table 2) represent the total tonnage multiplied by the proportions of different classes of ore for each orebody.

The amount of sulfur in the measurable ore in the oxidized and unoxidized zones was calculated statistically for each orebody, and the overall averages as computed were increased slightly in some instances to allow for the inclusion of unoxidized, high-sulfur ore below drill holes.

Owing to the widely spaced sampling and the difficulty of making adequate correlations between sections, the accuracy with which ore can be classified according to blocks does not seem to support much refinement of reserve figures. It also appears unlikely that accurate detailed corre-

lations between sulfur and iron content can be made at this stage of exploration.

About 30 percent of the reserves of measurable ore of all grades is estimated to contain more than 50 percent iron and less than 0.2 percent sulfur and thus could be shipped directly to blast furnaces without beneficiation. About half of this shipping ore is in the South deposit, as shown in table 3.

Table 3—Estimated proportions of direct shipping ore and mill ore

Deposit	*Direct-shipping ore*		*Mill ore*	
	Millions of long tons	*Percent of deposit*	*Millions of long tons*	*Percent of deposit*
North deposit	2.5	15	13.5	85
South deposit	4.2	65	2.5	35
Bald Eagle deposit	2.0	40	3.0	60
Totals	8.7	31	19.0	69

Mill ore as estimated in the above table would have to be treated to remove sulfur, or to increase the iron content, or both. Sink-and-float tests conducted by the metallurgical division of the Bureau of Mines, United States Department of the Interior, on oxidized middle-grade ore from the Eagle Mountains produced an efficient concentration of iron and a marked reduction in sulfur and phosphorous content.

Should mining be done in open pits with walls becoming ultimately as steep as 45 degrees, it is estimated that about 30 percent of measurable reserves, or about 8 million tons, could be mined without removal of any overburden, and about 75 percent, or 20 million tons, could be mined before the ratio of overburden to ore reached 2 to 1. Under the same assumptions, 3 to 4 million tons of inferred ore might be mined from open pits.

Reserve figures obtained by the Bureau of Mines, United States Department of the Interior, agree on the whole with those given in table 2. Bureau estimates as of July 1, 1942, give 21.6 million tons of ore above drill holes and between trenches, and 13 million tons of "geologic" (inferred) ore as compared with 28 million tons of measurable ore and 15 million tons of inferred ore in this report. The chief points of difference are explained as follows:

(1) Bureau estimates of ore indicated by trenching and drilling exclude 2.7 million tons of ore between 30 percent and 40 percent iron and about 3.5 million tons of ore of all grades below drill holes and beyond trenches. The writer has included this ore, amounting to 6.2 million tons, in his estimates of measurable ore.

(2) Because ore of lower grade is included, the average iron content of the principal deposits given in this report is lower than that of the Bureau by 1 or 2 percent Fe.

(3) "Geologic" ore estimated by the Bureau includes the 3.5 million tons below and beyond drill holes and trenches mentioned under (1) as well as most of classes A and B of inferred ore in table 2, altogether about 11 million tons.

(4) Most of the 7 million tons of inferred ore, class C, was not included in Bureau estimates.

BIBLIOGRAPHY

Boalich, E. S.
23 Notes on iron ore occurrences in California: California Min. Bur. Rept. 18, p. 111, 1923.

Burchard, Ernest F.
13 Iron ore, pig iron, and steel: Mineral Resources U. S., 1912, pt. 1, pp. 172-176, 1913.

Harder, Edmund Cecil
12 Iron-ore deposits of the Eagle Mountains, California: U. S. Geol. Survey Bull. 503, 81 pp., 4 figs., 13 pls., 1912.

Hodge, Edwin T.
35 Report on available raw materials for a Pacific Coast iron industry; 5 vols., 1935. War Dept., Corps Eng., U. S. Army, Office of Div. Eng., North Pacific Div., Portland, Oregon. *Eagle Mountains deposits*: vol. 1, p. 43; vol. 3, ap. E-5, p. 13.

Jones, Charles Colcock
16 The Pacific Coast iron situation—the iron ores of California and possibilities of smelting: Am. Inst. Min. Eng. Trans., vol. 53, pp. 307-308, 1916.

Merrill, Frederick J. H.
19a Riverside County: California Min. Bur. Rept. 15, pp. 544-545, 1919.

Miller, W. J.
44 Geology of Palm Springs-Blythe strip, Riverside County, California: California Div. Mines Rept. 40, pp. 31-32, 1944.

Schrader, F. C., Stone, R. W., and Sanford, S.
17 Useful minerals of the United States: U. S. Geol. Survey Bull. 624, p. 64, 1917.

Tucker, W. Burling
21 Los Angeles field division: California Min. Bur. Rept. 17, p. 327, 1921.
24 Los Angeles field division: California Min. Bur. Rept. 20, p. 196, 1924.

Tucker, W. B., and Sampson, R. J.
29 Riverside County: California Div. Mines Rept. 25, pp. 489-491, 1929.

United States Bureau of Mines
43 Eagle Mountains iron district, Riverside County, Calif.: U. S. Bur. Mines, War Minerals Rept. 97, 44 pp., 8 figs., 1943.

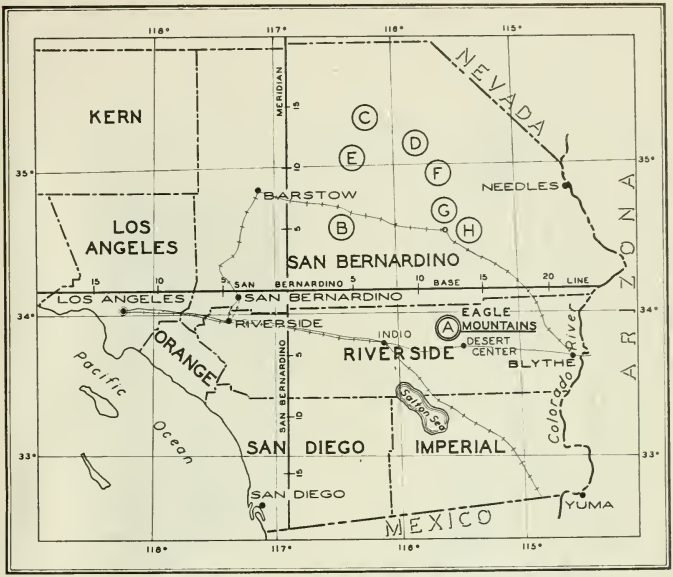

FIG. 1. Index map of southern California iron-ore deposits showing (A) EAGLE MOUNTAINS (described in this report); (B) Iron Mountain (Lava Bed); (C) Iron Mountain (Silver Lake); (D) Old Dad Mountain; (E) Cave Canyon; (F) Vulcan; (G) Iron Hat; (H) Ship Mountains.

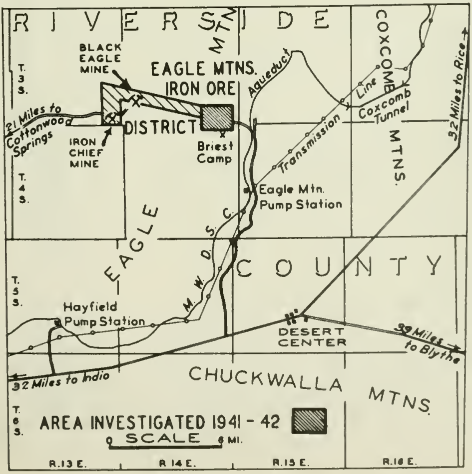

FIG. 2. Index map of a part of Riverside County showing location of Eagle Mountains iron-ore district.

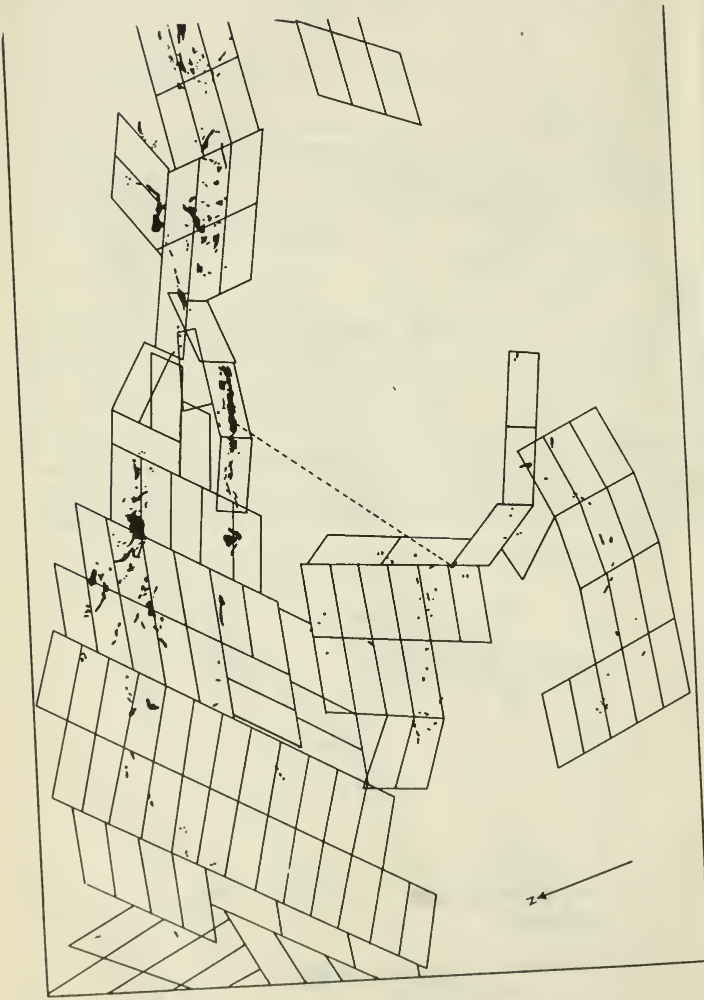

Illustration continued on page 19. Read from left to right.

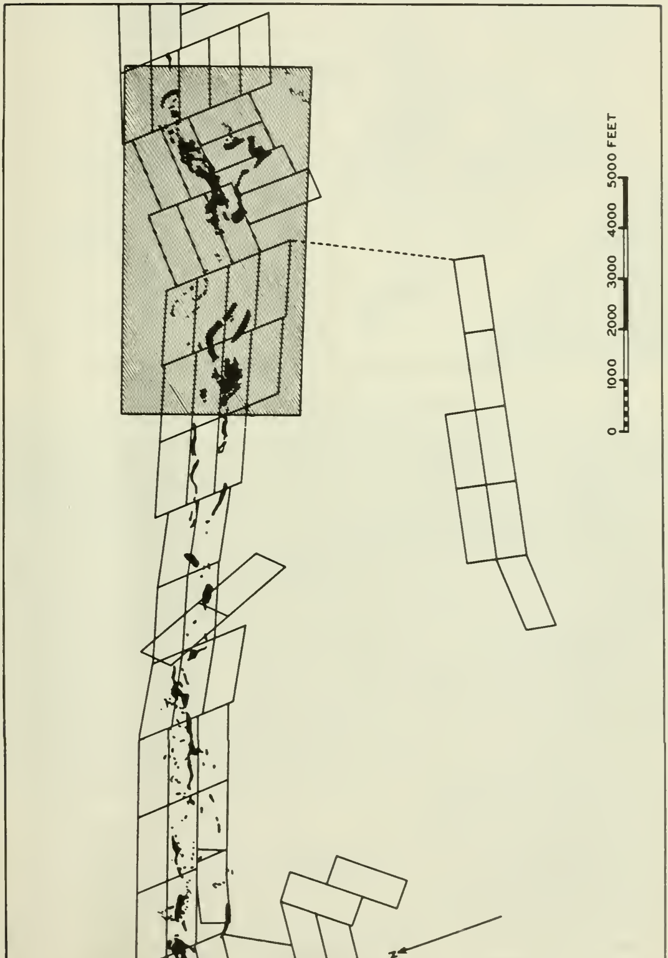

FIG. 3. Map showing the distribution of iron-ore deposits on mining claims of the Eagle Mountain district, by E. C. Harder and J. L. Rich (U. S. Geol. Survey Bull. 503, Pl. 8), 1912. (The eastern 25 claims, which occupy about one-fifth of the length of the entire range, comprise the area described in the present report.)

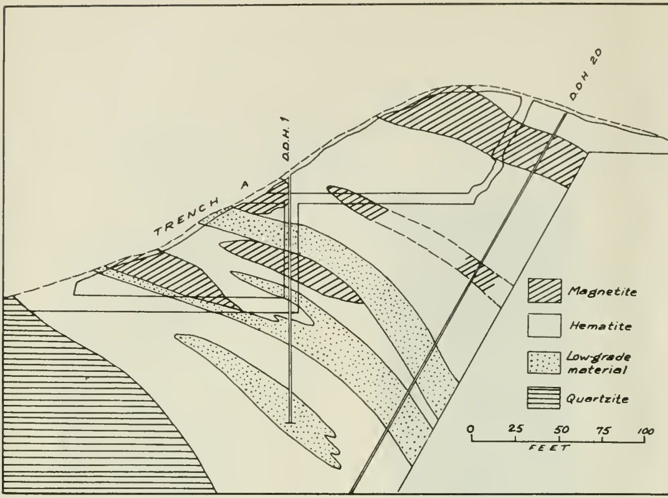

FIG. 4. Distribution of magnetite and hematite in part of structure section A-A', North deposit.

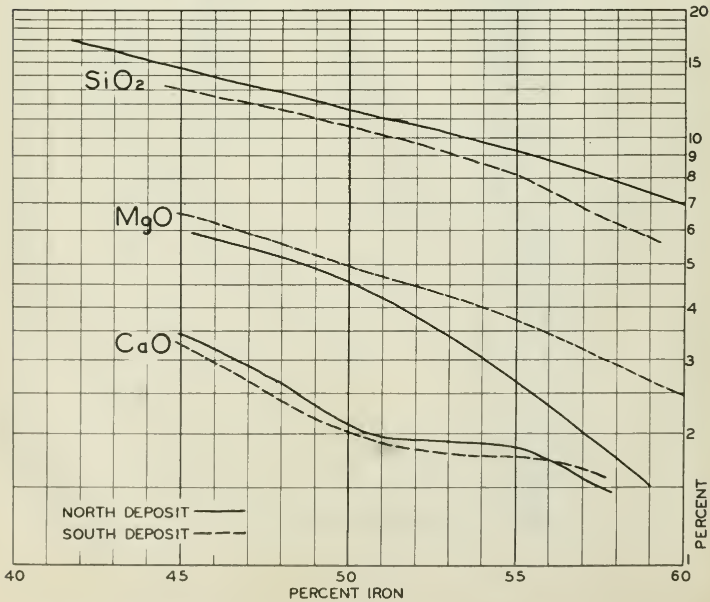

FIG. 5. Graph showing silica, magnesia, and lime in Eagle Mountains iron-ore deposits, based on 19 composite sludge samples from North deposit, 11 from South

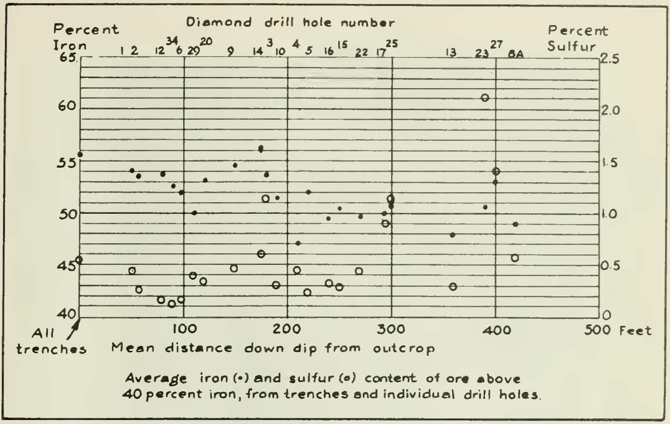

FIG. 6. Graph showing changes in iron and sulfur content with depth, in ore containing more than 40 percent iron, North deposit.

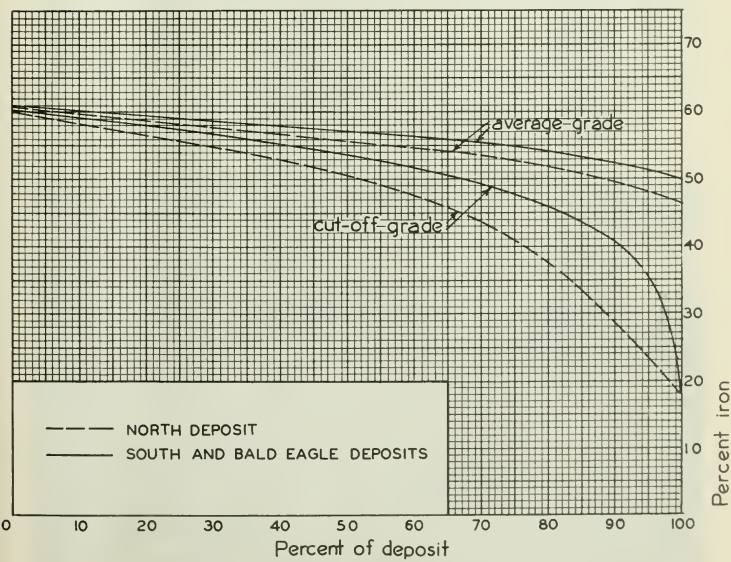

FIG. 7. Graph showing relation of reserves to average grades and cut-off grades of iron in Eagle Mountains deposits. For example: Ore containing more than 45 percent iron constitutes 67 percent of the North deposit and averages 50 percent iron; ore containing more than 45 percent iron constitutes 82 percent of the South and Bald Eagle deposits and averages 54 percent iron.

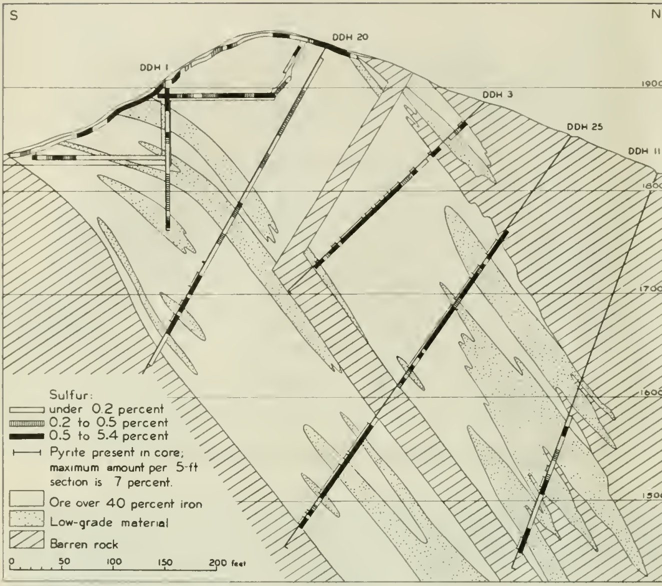

FIG. 8. Distribution of sulfur and pyrite in part of structure section A-A′, North deposit.

FIG. 9. Diamond-drill rig at hole 57, at east end of Bald Eagle deposits. The ore here is covered by 27 feet of bouldery gravel.

FIG. 10. Bald Eagle deposits seen from the east. Short white lines are trenches—lower group, left to right: P, Q, R, S, T, and U; upper group, bottom to top: U, V, and W. Bald Eagle Canyon in foreground, Big Dry Wash at left. Iron-ore-bearing area extends westward through the saddle just left of the center of picture.

Fig. 11. North deposit on North Hill, seen from the southeast. Irregular white lines across the hill in the center of the picture are trenches (left to right, B, A, G, H, and I). Other white lines are trails. U. S. Bureau of Mines field buildings and road to Desert Center at lower right.

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
WALTER W. BRADLEY, State Mineralogist

GEOLOGIC BRANCH
FERRY BUILDING, SAN FRANCISCO

OLAF P. JENKINS
Chief Geologist

SAN FRANCISCO] BULLETIN No. 129—PART B [JUNE 1945

Iron Resources of California
Bulletin No. 129

PART B

Iron Mountain Iron-Ore Deposits
Lava Bed District
San Bernardino County, California

By CARL A. LAMEY
Geological Survey, U. S. Department of the Interior

Issued by the
STATE DIVISION OF MINES

3—41420

IRON MOUNTAIN IRON-ORE DEPOSITS, LAVA BED DISTRICT, SAN BERNARDINO COUNTY, CALIFORNIA *

By Carl A. Lamey **

United States Department of the Interior, Geological Survey

OUTLINE OF REPORT

ABSTRACT

About 38 miles southeast of Barstow, California, in the desert area of San Bernardino County, 14 small contact-metamorphic and replacement iron-ore bodies scattered over an area of 80 acres constitute the Iron Mountain group of deposits. These deposits probably contain about 1,800,000 tons of ore, not more than 25 percent of which is workable at normal peacetime prices. The four largest of the 14 orebodies referred to contain 72 percent of the tonnage, or 1,300,000 tons.

Four miles south of the Iron Mountain group an iron-ore deposit of the same type, almost completely covered by alluvium, is thought to contain 3,300,000 tons of ore per 100 feet of depth. Other less important orebodies make up the remainder, or 250,000 tons, of the total reserves.

The total ore reserves from all the deposits in the area are estimated to be at least 5,350,000 tons, most of which is workable under emergency prices only. No ore has been produced from any of these deposits.

The orebodies occur at the contact between dolomite of unknown age and granitic rocks intrusive into it, and also entirely within the granitic rocks. Remnants of sedimentary rocks associated with the orebodies that lie wholly within granite and syenite indicate that the orebodies are the remains of roof pendants.

The larger orebodies are composed almost entirely of masses of magnetite, but they contain also magnetite disseminated throughout dolomite. Some smaller bodies consist of magnetite disseminated throughout a serpentine matrix or throughout a rock resembling sericitic quartzite.

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** Geologist, Geological Survey, U. S. Department of the Interior.

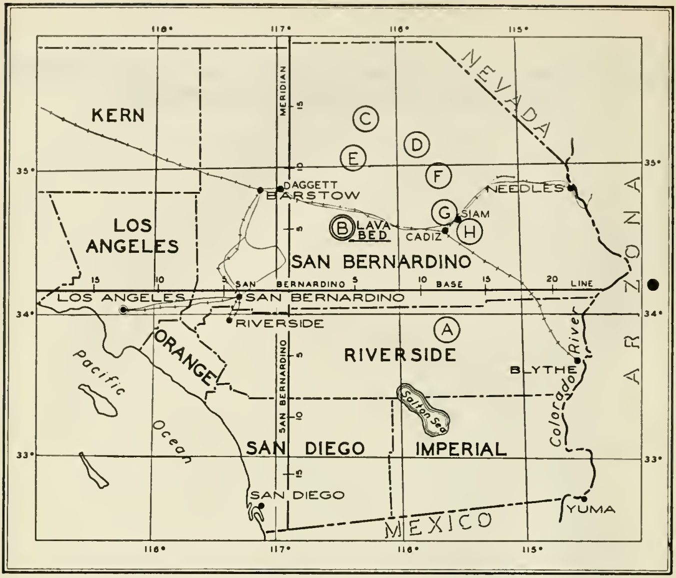


FIG. 12. Index map of southern California iron-ore deposits, showing: (A) Eagle Mountains; (B) IRON MOUNTAIN (LAVA BED), described in this report; (C) Iron Mountain (Silver Lake); (D) Old Dad Mountain; (E) Cave Canyon; (F) Vulcan; (G) Iron Hat; (H) Ship Mountains.

INTRODUCTION

The Iron Mountain iron-ore deposits are in the Mojave Desert, about 38 miles southeast of Barstow, California, (fig. 12), in secs. 27 and 28, T. 6 N., R. 4 E., S.B., San Bernardino County. Nearby, in secs. 15 and 36 of the same township, and in sec. 12, T. 5 N., R. 4 E., there are several other small iron-ore bodies. All of these deposits are in the Lava Bed district. They were examined during December 1942, by Carl A. Lamey, Preston E. Hotz, and Stanley E. Good.

The deposits are reached by a narrow, rough, dirt road, through the Ord Mountains south of Daggett and thence along an alluvium-filled valley. At some places in the valley the road passes through much loose sand. The deposits in secs. 27 and 28 are about 30 miles from Daggett, a station on the Atchison, Topeka, and Santa Fe Railway, but the deposits in secs. 36 and 12 are about 5 miles farther southeast. The railroad station at Lavic is closer to all of these deposits, as it is only about 16 miles from Iron Mountain. Also, 7 miles of dirt road extends from the deposits toward Lavic. However, completion of this road and haulage to Lavic is impractical at present, as the road passes through a United States Army bombing range.

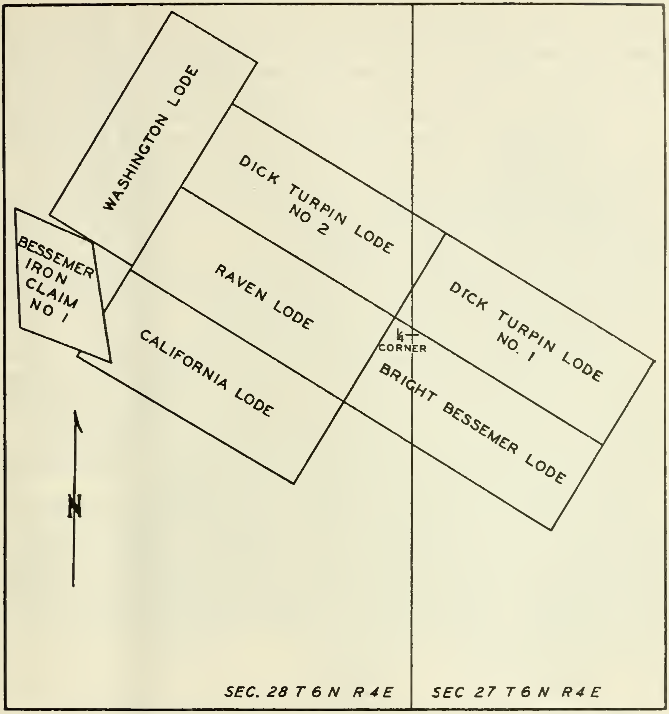


FIG. 13. Map showing location of claims, Iron Mountain iron-ore deposits, Lava Bed district, San Bernardino County. Compiled from map furnished by Edward E. Morris, president, Western Iron Mines.

The area containing the deposits is characterized by a series of ridges and valleys, and by interior drainage. The drainage is eastward and follows the regional slope of the principal valley. Alluvium partly fills the valleys, masks the lower slopes of the mountains, and almost buries some of the smaller hills.

The ore deposits lie chiefly along the lower slopes of the mountains. The deposits in secs. 27 and 28 are at altitudes ranging from 3,100 to 3,400 feet, but those in secs. 36 and 12 are at altitudes ranging from 2,000 to 2,400 feet.

No water is available in the immediate vicinity, and it is unlikely that water could be obtained closer than Daggett. It has been reported that water might be found toward the eastern end of the valley but this is doubtful.

The present owner of the deposits in secs. 15, 27, and 28 is Western Iron Mines, 649 South Olive Street, Los Angeles, California. Mr. Edward E. Morris is president of this company. The property in secs.

27 and 28 was obtained from Union Oil Company on May 1, 1942. It comprises seven claims totaling about 130 acres (fig. 13), which were formerly owned by Mrs. Phoebe Owens, San Francisco, and E. S. Lake, Los Angeles.[1] Western Iron Mines also owns a block of 18 claims adjoining this property to the southeast and extending through parts of secs. 27, 26, 34, and 35.[2] These additional claims are in an alluvium-covered area in which neither surface indications nor prospect pits disclose the presence of iron ore. Ownership of the deposits in secs. 36 and 12 is unknown. It is reported that they are owned by Union Oil Company.

Published material relating to these deposits is found chiefly in the Annual Reports of the State Mineralogist of California,[3] and in Mineral Abstracts.[4] These publications state that the ore at Iron Mountain forms well-defined veins in dolomitic limestone and syenite, and that the deposit may contain as much as 10,000,000 tons of commercial ore. One analysis of ore shows: iron, 65 percent; silica, 5.5 percent; sulphur, 0.06 percent; phosphorous, 0.045 percent.

A considerable amount of exploratory work has been done in this area, but no ore has been produced. In secs. 27 and 28 there are a number of shallow pits and trenches; a few small adits, the longest of which is 25 feet; and a few shafts, the deepest of which is 75 feet. One headframe and one chute have been built, both of which are inadequate for anything except very minor production. Developments in secs. 15, 36, and 12 consist of shallow exploration pits.

Field mapping was done by means of plane table and telescopic alidade, using a taped base line 2,000 feet long for control. The altitude of one station was assumed to be 3,060 feet. This assumption was based on barometric readings taken at the station and at a bench mark at Daggett. True north was determined by means of the Baldwin solar chart. The dip needle was used as an aid in outlining the limits of the orebodies.

GEOLOGY

Rock Units

The major rock units exposed that are associated with the iron-ore deposits include (1) dolomite or dolomitic limestone, (2) granitic rocks intrusive into the dolomite, and (3) alluvium. The geologic age of the rocks is not definitely known, but the relative age, from oldest to youngest, is that stated above.

The granitic rocks form the main part of the mountains (see Pl. IV), and both the iron ore and the dolomite form numerous disconnected patches that lie within the granitic mass and around its periphery. Minor amounts of quartzite form lenses and beds in the dolomite, from which they were not separated in mapping.

The dolomite is chiefly white to light bluish gray. One type is mottled in brown and white, or spotted with light brown, and becomes pitted or cellular on weathering. Another type is banded in white and light brown. The texture of the dolomite varies from finely

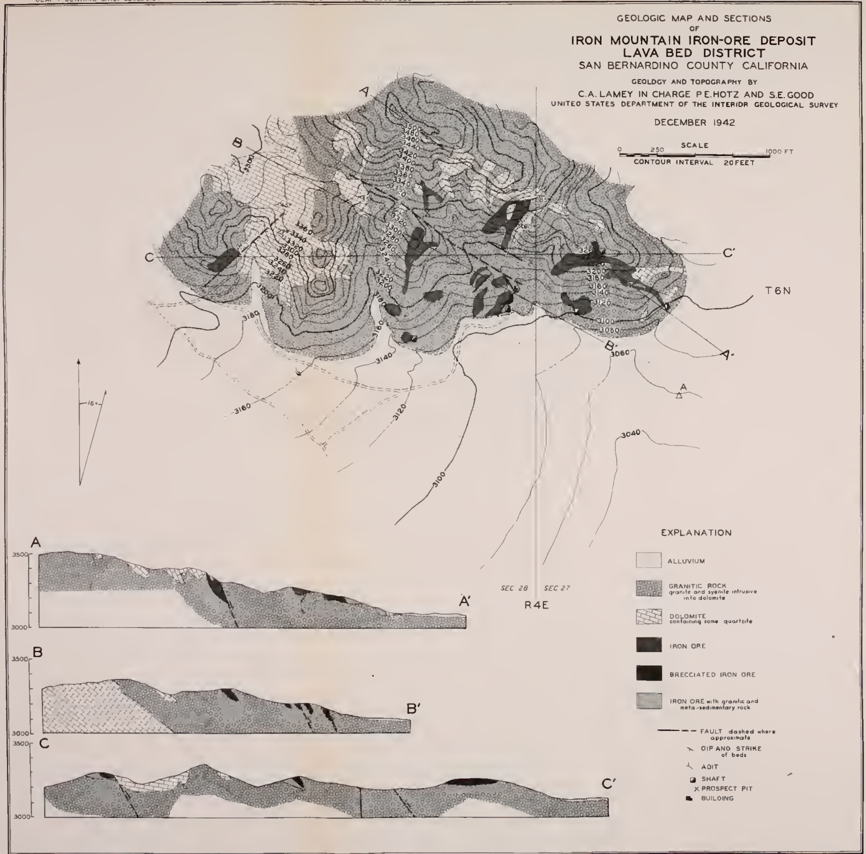
[1] Iron Mountain deposit: California Div. Mines, Min. Abstracts, Iron, p. 27, 1941.

[2] Acknowledgment is due to Mr. Edward E. Morris for copy of a map showing claims owned by Western Iron Mines.

[3] Cloudman, H. C., Huguenin, E., and Merrill, F. J. H., San Bernardino County: California Min. Bur. Rept. 15, pp. 819-820, 1915, 1916; Tucker, W. B., and Sampson, R. J., San Bernardino County: California Div. Mines Rept. 27 p. 335, 1931; Tucker, W. B., and Sampson, R. J., Economic mineral deposits of the Newberry and Ord Mountains, San Bernardino County: California Div. Mines Rept. 36, p. 241, 1940.

[4] Op. cit.

be the remains of roof pendants.


GEOLOGIC MAP AND SECTIONS
OF
IRON MOUNTAIN IRON-ORE DEPOSIT
LAVA BED DISTRICT
SAN BERNARDINO COUNTY CALIFORNIA
GEOLOGY AND TOPOGRAPHY BY
C.A. LAMEY IN CHARGE P.E.HOTZ AND S.E.GOOD
UNITED STATES DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY
DECEMBER 1942
SCALE
0 250 1000 FT
CONTOUR INTERVAL 20 FEET
A
B
C
C'
B'
A'
T6N
SEC 28
SEC 27
R4E
16°
EXPLANATION
ALLUVIUM
GRANITIC ROCK granite and syenite intrusive into dolomite
DOLOMITE containing some quartzite
IRON ORE
BRECCIATED IRON ORE
IRON ORE with granitic and meta-sedimentary rock
FAULT dashed where approximate
DIP AND STRIKE of beds
ADIT
SHAFT
X PROSPECT PIT
BUILDING
3500
3000

crystalline and sugary to coarsely crystalline; locally, individual rhombs of the latter type are as much as an inch across. Lenses and beds of quartzite associated with the dolomite vary from grayish, possibly argillaceous quartzite to nearly white, vitreous quartzite. Individual quartz grains show clearly in each variety.

The granitic rocks include white to gray granite and syenite. The granite ranges from fine-grained to coarse-grained and pegmatitic types. It is composed chiefly of quartz and orthoclase or microcline, but contains some biotite and perhaps some hornblende. The syenite is coarsely crystalline to pegmatitic. It is composed chiefly of orthoclase or microcline and hornblende. Biotite is present also, and locally it is the dominant dark mineral.

The alluvium is composed of sand and gravel.

The iron ore with which these rocks are associated is chiefly black magnetite, but is composed in part of red hematite and brown limonite. Much of the magnetite is coarsely crystalline. Zones of brown to green metamorphic rock composed chiefly of garnet, epidote, and pyroxene are associated with the ore, and locally a fibrous, bluish-green anthophyllite (?), or a white tremolite, is present.

Structure

The attitude of the dolomite is the most important structural feature of the rocks. Generally it strikes northeast and dips from 30° to 40° SE., but both the strike and the dip vary considerably, especially near intrusive contacts. Locally the dolomite dips nearly 90°, either toward or away from the granitic rocks. The attitude of the dolomite was an important factor in localizing the orebodies, many of which trend north to northeast and pitch southeast.

The faults of the area trend northeast and northwest. At least some faults are later than the ore formation, and movement along them has caused brecciation of the ore. This is especially apparent in the orebody immediately west of the quarter corner between secs. 27 and 28.

ORE DEPOSITS

Relative Importance

The most extensive and important orebodies are those in secs. 27 and 28, T. 6 N., R. 4 E., and in sec. 12, T. 5 N., R. 4 E. (see fig. 14). The deposits in secs. 15 and 36, T. 6 N., R. 4 E., are of minor importance. In secs. 27 and 28, chiefly within 1,000 feet of the quarter corner between those sections, there are 14 orebodies that contain most of the ore of the area. In the NE$\frac{1}{4}$ sec. 12, magnetic attraction indicates the presence of one large orebody almost completely covered by alluvium. This body may contain more ore than any other in the area.

Features Characteristic of Most Deposits

Occurrence

The ore occurs as irregular to pod-like bodies near the contact between dolomite and granitic rocks, or entirely enclosed within the latter rocks. The bodies that lie within the granitic rocks have small remnants of metamorphosed sediments associated with them, and may be the remains of roof pendants.

Mountains, San Bernardino County: California Div. Mines Rept. 36, p. 241, 1940.
[4] Op. cit.

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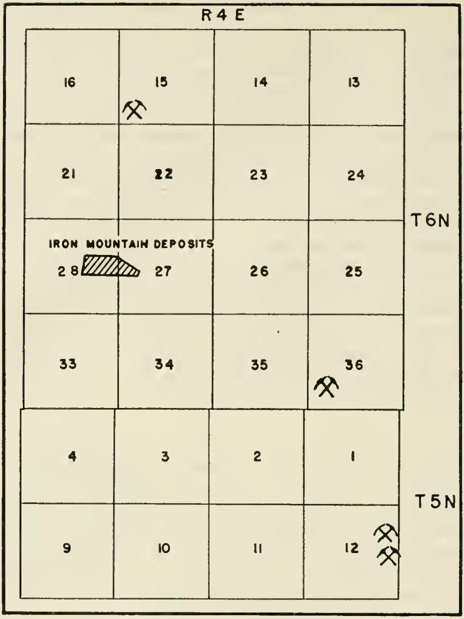

Fig. 14. Sketch map showing location of iron-ore deposits of Lava Bed district.

Mineralogy

Some of the orebodies are relatively free from gangue minerals, others contain both gangue minerals and ore minerals intimately associated. Locally the gangue minerals constitute as much as half of the orebody.

Ore Minerals and Gangue Minerals. The ore minerals of the deposits are simple iron oxides, whereas the gangue minerals are chiefly silicates. A list of most of the minerals present in the deposits follows (see page 33). The minerals were identified megascopically.

Magnetite is the chief ore mineral, but both hematite and limonite are present. The magnetite forms finely crystalline to coarsely crystalline masses, the latter containing octahedra as much as an inch across. The hematite is slightly gray to red and is usually rather earthy. The limonite is light brown and ocherous.

Brown garnet, pistachio-green epidote, and a dark-green pyroxene, possibly some member of the diposide-hedenbergite series, are the most characteristic gangue minerals associated with the ore, but calcite, and perhaps dolomite, are usually present also. The garnet usually is more abundant than the epidote or the pyroxene. These three minerals are the characteristic constituents of the zone of contact rock (skarn) that

Minerals present in Iron Mountain iron-ore deposits

Ore Minerals	
Magnetite	Fe_3O_4
Hematite	Fe_2O_3
Limonite	$2Fe_2O_3.3H_2O$
More Abundant Gangue Minerals	
Garnet	$Ca_3Fe_2(SiO_4)_3$
Epidote	$HCa_2(Al, Fe)_3Si_3O_{13}$
Pyroxene	$Ca(Mg,Fe)Si_2O_6$
Calcite	$CaCO_3$
Dolomite	$CaMg(CO_3)_2$
Less Abundant Gangue Minerals	
Tremolite	$CaMg_3(SiO_4)_3$
Anthophyllite	$(Mg,Fe)SiO_3$
White mica	$H_2KAl_3(SiO_4)_3(?)$
Serpentine	$H_4Mg_3Si_2O_9$
Chondrodite	$[Mg(Fe,OH)]_2Mg_3(SiO_4)_2$
Quartz	SiO_2
Chalcedony	SiO_2

separates the ore from the granitic rock and forms one wall of the deposit. Locally a bluish-green, fibrous mineral, possibly anthophyllite, and more rarely a white tremolite, are present in the contact zone. As a rule the minerals of the contact zone are separated sharply from the ore minerals. Calcite, and perhaps dolomite, are more or less admixed with the ore minerals in every deposit.

White mica, sericite, yellowish-green serpentine, and a brownish-yellow mineral resembling chondrodite are abundant locally, but these minerals usually occur separately, not associated with one another. Where they are present these minerals are intimately associated with the ore minerals. Typical occurrences are (1) well crystallized white mica in vugs associated with magnetite; (2) serpentine as a matrix surrounding magnetite; and (3) chondrodite between bands and disseminated crystals of magnetite in a rock resembling sericitic quartzite.

Quartz and chalcedony are present in some quantity along faults and small shear zones.

Mineral Paragenesis. Field evidence indicates that garnet, epidote, and pyroxene, the characteristic silicates of the contact zone, formed first, and that magnetite was later introduced. White mica apparently crystallized contemporaneously with magnetite. Serpentine may have been formed by hydrothermal alteration of dolomite after the introduction of magnetite, but this relation is not definitely established by megascopic examination. Calcite and dolomite formed by recrystallization of the original dolomite, but some secondary calcite was introduced later. Hematite, limonite, quartz, and chalcedony are secondary minerals.

Mode of Origin

Field evidence clearly indicates that the ore deposits originated as contact-metamorphic bodies and replacements, and that they were formed by intrusion of granitic rocks into dolomite. This mode of origin is suggested by the following facts:

1. The orebodies occur at the contact between dolomite and granitic rocks, or entirely within the granitic rocks. At the latter places remnants of dolomite are

associated with the ore, indicating that the orebodies represent the remains of roof pendants.

2. A zone of typical contact-metamorphic minerals is a characteristic associate of most orebodies.

3. Magnetite occurs along lines of bedding in dolomite, forming a banded rock composed of magnetite and dolomite. The magnetite bands apparently were formed by selective replacement along bedding planes in dolomite.

4. A mottled and spotted magnetite-dolomite rock resembling the mottled and spotted type of dolomite, with magnetite substituting for the brownish spots of the latter, suggests replacement by magnetite.

5. Banding and mottling in the serpentine-bearing ore and in the chondrodite or quartzite types of ore suggests that these features probably resulted from replacement along lines of original sedimentary structures.

Specific Characteristics of Certain Deposits

Deposits in Secs. 27 and 28, T. 6 N., R. 4 E. Fourteen patches of iron ore occur in secs. 27 and 28 (Pl. IV). The largest one covers an area of about 50,000 square feet, the smallest one an area of about 2,500 square feet. Most of the ore is contained in the four largest orebodies of the group.

Ores of several types are present in this area. Accurate classification is precluded by lack of analyses of the ore, but field estimates of percentages of iron, combined with other features, make possible the following rough grouping.

Types of ore present in secs. 27 and 28

		Percent iron
Group 1.	*Ore masses in dolomite and granitic rock*	
	a. Composed chiefly of relatively pure magnetite with some hematite and limonite	60–65
	b. Composed chiefly of magnetite with some hematite and limonite, but containing variable amounts of included rock	40–60
Group 2.	*Disseminated ore*	
	a. In dolomite	30–40
	b. In serpentine matrix	30–40
	c. In rock resembling sericitic quartzite	30–40
Group 3.	*Both ore masses and disseminated ore*	
	Deposits contain considerable amounts of included rock. Iron content extremely variable	30–50
Group 4.	*Brecciated ore*	
	Deposits contain rock masses of variable size. Iron content extremely variable	30–60

Deposit in Sec. 15, T. 6 N., R. 4 E. About $1\frac{1}{2}$ miles north of the Iron Mountain orebodies, in the SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 15, there is a deposit similar to the deposits in secs. 27 and 28. Iron ore is present in an area about 500 feet long and 20 to 30 feet wide, which has a general northeast trend. The deposit is not a single orebody but consists of several patches of ore. The principal associated rocks are hornblende syenite and dolomite. A section across this area, from north to south, follows.

North-south section across ore deposit in sec. 15

1. Hornblende syenite
2. Contact silicate zone about 20 feet wide containing garnet, epidote, anthophyllite (?) and tremolite
3. Ore zone from 20 to 30 feet wide, containing magnetite and some hematite and dolomite

4. Dolomitic marble dipping steeply northward
5. Contact silicate zone a few feet wide
6. Hornblende syenite

This deposit lies at an altitude of about 3,800 feet, nearly 500 feet higher than the deposits of the Iron Mountain group. It is separated from the latter deposits by mountains composed almost entirely of granite and syenite.

Deposit in Sec. 36, T. 6 N., R. 4 E. In the SW¼ sec. 36, southeast of the Iron Mountain orebodies, a small limonite deposit is exposed by a number of pits and trenches. A very small amount of magnetite is present at a few places. Most of the exposed rock in this area is granite, and the limonite occurs as a gossan along a large fault zone in the granite. Claim notices in the vicinity indicate that prospecting was for gold rather than for iron.

Deposits in Sec. 12, T. 5 N., R. 4 E. A sketch map of the deposits in sec. 12 (fig. 15), about 1½ miles south of sec. 36, shows that conditions are similar to those at Iron Mountain. The deposits are in two principal areas.

In the SE¼ of the section an area of about 150,000 square feet contains a number of small bodies of magnetite, hematite, and limonite, accompanied by much admixed rock. Large zones of contact-metamorphic silicates are present, but apparently there is very little iron ore associated with them. The surface exposures of ore indicate that the small deposits are likely to be shallow, and that the subsurface parts of the deposits may contain more rock than the exposed parts.

In the NE¼ of this section, at altitudes ranging from about 2,200 to 2,300 feet, strong magnetic attraction indicates the presence of an orebody approximately 1,100 feet long and 300 feet wide, almost completely covered by alluvium. It lies between a small granitic knob and a ridge of dolomite, and follows in part the eastern side of the dolomite. Small exposures and magnetic attraction indicate that the ore mineral is chiefly magnetite.

ORE RESERVES

Estimates of ore reserves are based chiefly on the topographic position of the orebodies and the amount of ore exposed at the surface. Nearly all pits and trenches are shallow and furnish very little information that is not shown by outcrops.

Composition of samples collected and analyzed by the Kaiser Company, Inc., Iron Mountain iron-ore deposits, Lava Bed District, San Bernardino County, California

		Percent		
Fe	P	SiO_2	S	CaO
58.70	----	----	----	---
19.35	0.088	21.19	0.009	9.25
20.56	0.072	21.20	0.251	8.58

There has been no systematic sampling of the deposits by the U. S. Geological Survey, but the analyses of three samples collected and analyzed by the Kaiser Company, Inc., have been released for publication and are given above. The exact location of these samples is not given, but presumably they are in secs. 27 and 28.

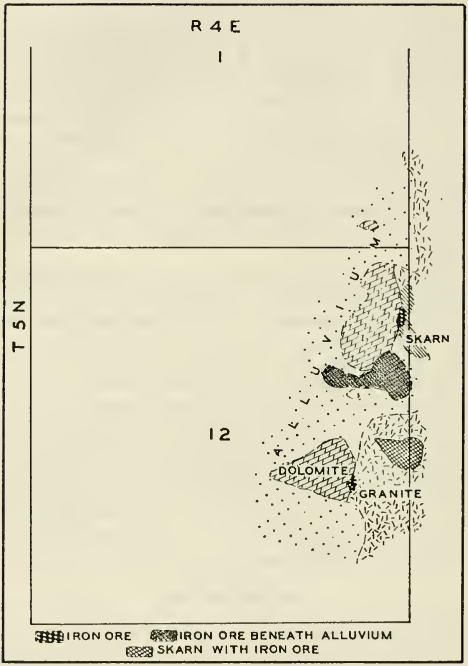

FIG. 15. Geologic sketch map of a pace and compass survey of iron-ore deposits in sec. 12, T. 5 N., R. 4 E., Lava Bed district.

The U. S. Bureau of Mines reports that deposits in sec. 12 (Bessemer Iron, project 918) average about 38 percent iron.[5]

All reserves are classed as inferred ore. The largest reserves are in secs. 27 and 28, and in sec. 12.

Deposits in Secs. 27 and 28, T. 6 N., R. 4 E. The depth of ore in secs. 27 and 28 probably ranges from about 50 to 120 feet. A depth considerably greater than 120 feet seems improbable, as many of the orebodies apparently are small roof pendants projecting into the granitic rocks. The tonnage of each type of ore in these sections is stated in the following tabulation.

Ore reserves in Secs. 27 and 28

Type of ore	*Estimated iron content, percent*	*Inferred ore, long tons*
Group 1. *Ore masses in dolomite and granitic rock*		
a. Composed chiefly of relatively pure magnetite but including some hematite and limonite	60-65	240,000
b. Composed chiefly of magnetite, but including some hematite and limonite, and containing variable amounts of included rock	40-60	725,000
Group 2. *Disseminated ore*		
a. In dolomite	30-40	140,000
b. In serpentine matrix	30-40	40,000
c. In rock resembling sericitic quartzite	30-40	115,000
Group 3. *Both ore masses and disseminated ore*		
Deposits contain considerable amounts of included rock. Iron content extremely variable	30-50	480,000
Group 4. *Brecciated ore*		
Deposits contain rock masses of variable size. Iron content extremely variable	30-60	60,000
Total, all grades	30-65	1,800,000

Although the ore in secs. 27 and 28 is scattered throughout 14 orebodies, 72 percent of it, or 1,300,000 tons, is contained in the four largest deposits.

Because of the scattered nature of the deposits, the amount of included rock, the distance from railroad, the lack of water, and the probable cost of mining, probably not more than 25 percent of the ore in secs. 27 and 28 would be workable under normal peacetime prices. A subdivision of the reserves workable under normal and under emergency prices follows.

Ore reserves in secs. 27 and 28, workable under normal and under emergency prices

		Tons
Class 1.	Ore workable at normal peacetime prices	465,000
Class 2.	Ore workable at emergency prices only	1,040,000
Class 3.	Ore possibly workable under changed conditions, requiring crushing and concentration	295,000

Class 1 includes ore of group 1a, composed chiefly of relatively pure magnetite, and the richest ore of group 1b; class 3 includes ore of indi-

[5] Summary of Bureau of Mines exploration projects on deposits of raw material resources for steel production: U. S. Bureau of Mines, Report of Investigations No. 3801, pp. 7 and 10, 1945.

vidual bodies of disseminated deposits of group 2; and class 2 includes all remaining ore.

Deposit in Sec. 15, T. 6 N., R. 4 E. If the small deposit in sec. 15 extends to a depth of 100 feet, it contains approximately 125,000 tons of ore-bearing material, at least 25,000 tons of which is waste rock. Therefore this deposit contains only 100,000 tons of ore, which probably would analyze about 40 to 50 percent of iron. As it would be necessary to construct several miles of road to make this deposit accessible from the deposits in secs. 27 and 28, the ore probably could be recovered only in case of extreme emergency.

Deposit in Sec. 36, T. 6 N., R. 4 E. The deposit in sec. 36 is merely a thin gossan. It is not regarded as reserve ore.

Deposits in Sec. 12, T. 5 N., R. 4 E. The total amount of ore in the small bodies scattered through granite and limestone in the SE¼ sec. 12 is probably between 100,000 and 150,000 tons. The greater part of it probably contains a maximum of 40 percent of iron, although a small part of it may contain as much as 50 percent. These deposits contain more waste rock than ore. Hence they could be mined only in case of extreme emergency, even though they are relatively near a road.

The deposit beneath the alluvium in the NE¼ sec. 12 is thought to contain about 1,650,000 tons of ore if it is 50 feet thick, which is equivalent to 3,300,000 tons per 100 feet of depth. Because of the alluvium cover, little information was obtained about the character of this ore. It is highly magnetic and could well be very good ore, but lack of information makes it necessary to classify it as ore workable under emergency prices only.

Summary of Ore Reserves

The total estimated ore reserves in this area are at least 5,350,000 tons, almost all of which is workable under emergency prices only. The most important orebodies are the four largest ones in secs. 27 and 28, T. 6 N., R. 4 E., which contain about 1,300,000 tons of ore, and the large body in sec. 12, T. 5 N., R. 4 E., which contains about 3,300,000 tons of ore per 100 feet of depth. The other scattered deposits in secs. 15, 27 and 28, T. 6 N., R. 4 E. and in sec. 12, T. 5 N., R. 4 E., estimated to contain 750,000 tons of ore, make up the remainder of the reserves.

CONDITIONS AFFECTING MINING

Mining would be restricted to the deposits in secs. 27 and 28 and to the deposit in sec. 12, as many of the deposits are difficult of access and contain but small amounts of ore. Even in secs. 27 and 28 the wide separation of the deposits would interrupt the continuity of mining. About 60,000 tons of brecciated ore in sec. 27, at the base of a slope and immediately adjacent to the road, could be mined easily and relatively cheaply, but the cost of mining most of the ore would be high.

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
WALTER W. BRADLEY, State Mineralogist

GEOLOGIC BRANCH
FERRY BUILDING, SAN FRANCISCO

OLAF P. JENKINS
Chief Geologist

SAN FRANCISCO] BULLETIN No. 129—PART C [JUNE 1945

Iron Resources of California

Bulletin No. 129

PART C

Iron Mountain and Iron King Iron-Ore Deposits, Silver Lake District San Bernardino County, California

By CARL A. LAMEY
Geological Survey, U. S. Department of the Interior

Issued by the
STATE DIVISION OF MINES

IRON MOUNTAIN AND IRON KING IRON-ORE DEPOSITS, SILVER LAKE DISTRICT, SAN BERNARDINO COUNTY, CALIFORNIA *

By Carl A. Lamey **

United States Department of the Interior, Geological Survey

OUTLINE OF REPORT

ABSTRACT

The Iron Mountain and Iron King iron-ore deposits are in the Mojave Desert, about 12 miles west of the hamlet called Silver Lake, San Bernardino County, California. At Iron Mountain indicated reserves are estimated to be 5,175,000 long tons of high-grade ore, and inferred reserves to be about 1,000,000 long tons. The reserve at the Iron King deposits is probably about 375,000 long tons of ore.

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* Published by permission of the Director, Geological Survey, U. S. Department of the Interior. Manuscript submitted for publication September 28, 1944.

** Geologist, Geological Survey, U. S. Department of the Interior. Estimates of iron-ore reserves at Iron Mountain are by Thomas A. Steven, based on geologic work by James Gilluly.

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The ore is chiefly magnetite, much of it coarse grained, accompanied by lime silicates and unreplaced limestone. It forms lenses in a limestone breccia, which also encloses lenses of igneous and metamorphic rock. The orebodies are thought to consist of material that was derived from a contact-metamorphic deposit, redeposited as rubble or talus on an eroded sandstone surface, and perhaps brought to its present situation by thrust faulting. Such an origin is indicated by the association of magnetite, contact-metamorphic minerals, and partly replaced limestone in a bedded deposit that has not itself been contact metamorphosed. The source of the ore has not been found.

The age of the limestone breccia and the intercalated iron ore is not known, but as the breccia rests on Tertiary sandstone and conglomerate it is tentatively regarded as Tertiary. Adjacent igneous rocks in place are thought to be older than the sedimentary rocks, but that is not quite certain, because the contact between igneous and sedimentary rocks is faulted wherever exposed.

The geologic structure is highly complex and appears to be related to that of the Virgin Spring area in southern Death Valley. The Tertiary sandstone and the limestone breccia are highly folded, and locally dip as steeply as 75° to 90° or are even overturned. The rocks have been displaced both by thrust and by normal faults. Apparently at least three periods of movement have taken place, the latest of which was very recent, for some faults displaced the alluvium. Three or four miles northeast of Iron Mountain the limestone breccia ends abruptly, and all the outcrops of sedimentary rock beyond this break are of gray sandstone and fanglomerate. The limestone breccia appears to have been cut off by a great low-angle thrust fault, upon which gray sandstone beds have moved from the north. The ore deposits and the associated rocks of the Iron Mountain-Iron King area may well be part of a very extensive thrust belt, for in all directions, to distances of 15 to 40 miles, there are great low-angle thrust faults, and areas characterized by chaotic structure.

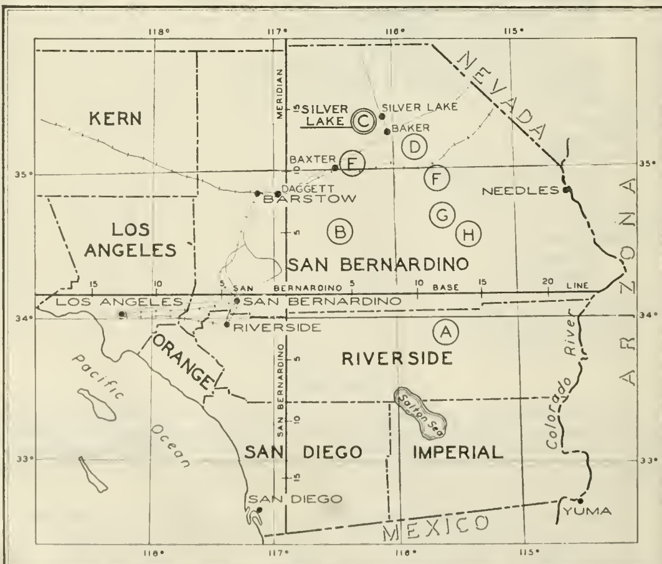


Fig. 16. Index map of southern California iron-ore deposits showing: (A) Eagle Mountains; (B) Iron Mountain (Lava Bed); (C) IRON MOUNTAIN (SILVER LAKE), described in this report; (D) Old Dad Mountain; (E) Cave Canyon; (F) Vulcan; (G) Iron Hat; (H) Ship Mountains.

INTRODUCTION

The Iron Mountain iron-ore deposits of the Silver Lake district are in the Mojave Desert, about 12 miles west of the hamlet called Silver Lake (fig. 16), which has a population of about 10 people. The deposits lie in secs. 11, 12, 13, and 14, T. 15 N., R. 6 E., S.B., San Bernardino County, California. The Iron King deposits are about 2 miles southeast of the Iron Mountain deposits, in secs. 18 and 19, T. 15 N., R. 7 E. All these deposits were examined, during January and February 1943, by Carl A. Lamey, assisted by Preston E. Hotz and Stanley E. Good, in order to determine the probable extent and availability of their ore. Mapping was done by means of telescopic alidade and plane table (Pl. VI). True north was determined by use of the Baldwin solar chart. In order to ascertain the relations of the ore deposits to the rocks of the mountain mass adjoining them to the southwest and west, a pace and compass sketch map was made of that area (Pl. V). In March 1944, the principal deposits at Iron Mountain were remapped by James Gilluly and J. A. Reinemund on a scale larger than the Lamey maps; and on the basis of their mapping, and core logs recorded by Gilluly from U. S. Bureau of Mines (Project 917) diamond-drill holes, a geologic map (Pl. VII) with a series of cross sections was prepared, thus furnishing a basis from which tonnage estimates were made. As Doctor Gilluly entered upon another assignment before he could finish his work on these data, the material was turned over to Thomas A. Steven for completion and calculation of reserves.

The area in which the Iron Mountain and Iron King deposits occur is characterized by ridges that rise 200 to 400 feet above alluvium-filled basins, which are about 2,000 feet above sea-level. The orebodies are on the slopes of some of the ridges. North of the deposits the Avawatz Mountains rise 3,000 to 5,000 feet above the basins; southwest and west of them is a smaller mountain mass, apparently an extension of the Avawatz Mountains, which rises about 1,500 feet above the basins.

The Iron Mountain orebodies are mostly on the east side of a series of north-south ridges, which have altitudes ranging from 2,300 to 2,440 feet, or about 1,400 to 1,540 feet higher than Silver Lake; they extend, in general, from the crests nearly to the feet of the ridges. The Iron King orebodies lie on the south side of a westward-trending ridge, near its crest, at altitudes ranging from 1,800 to 1,900 feet. At the Iron Mountain deposits there are six patented claims (fig. 17), and at the Iron King deposit there is but one patented claim (fig. 17). It is reported† that some of the ore has been shipped to the U. S. Bureau of Mines plant at Laramie, Wyoming, to be reduced to sponge iron, which will be subsequently used for making special steels at the Bureau's plant at Redding, California.

At Iron Mountain, according to published articles in which very little information is given except brief sketches of the geology, reserves amount to as much as 12,000,000 tons of high-grade iron ore; but such an estimate is, in the writer's opinion, excessive.

† Summary of Bureau of Mines exploration projects on deposits of raw material resources for steel production: U. S. Bureau of Mines, Report of Investigations No. 3801, p. 7, 1945.

The chief references follow:

The structural and industrial materials of California: California Min. Bur. Bull. 38, p. 299, 1906.

Iron Mountain group: California Div. Mines, Min. Abstracts, Iron, pp. 28-29, 1941.

Hodge, E. T., Available raw material for a Pacific Coast iron industry: War Dept., vol. 3, North Pacific Division, appendix E-5, California iron ore deposits, pp. 11-12, 1935.

Hewett, D. F., Callaghan, Eugene, Moore, B. N., Nolan, T. B., Rubey, W. W., and Schaller, W. T., Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, p. 78, 1936.

ACKNOWLEDGMENTS

The courtesies extended to the field party by Mr. Charles Reat, Silver Lake, California, are highly appreciated. Mr. T. R. Carpenter, County Recorder, San Bernardino County, California, kindly supplied a copy of the claim map of the Iron Mountain deposits, and Mr. John L. Warboys, District Cadastral Engineer, Public Survey Office, Glendale, California, a copy of the claim map of the Iron King deposit. Able field assistance was given by Mr. P. E. Hotz and Mr. S. E. Good, and Mr. L. F. Noble constructively criticized the manuscript. Credit is also given to James Gilluly and J. A. Reinemund who have done more recent mapping in the Iron Mountain area, and whose work, in conjunction with data obtained by Gilluly from diamond drill holes put down by the U. S. Bureau of Mines in connection with Project 917, furnished a basis for the calculation of the iron-ore reserves of this area by Thomas A. Steven.

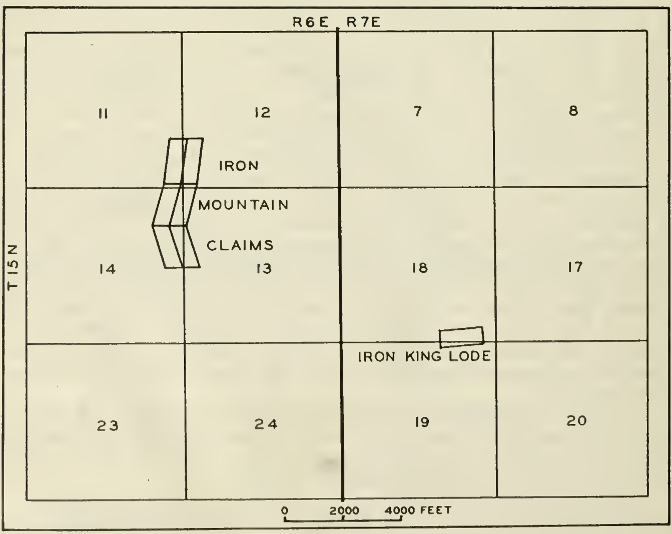
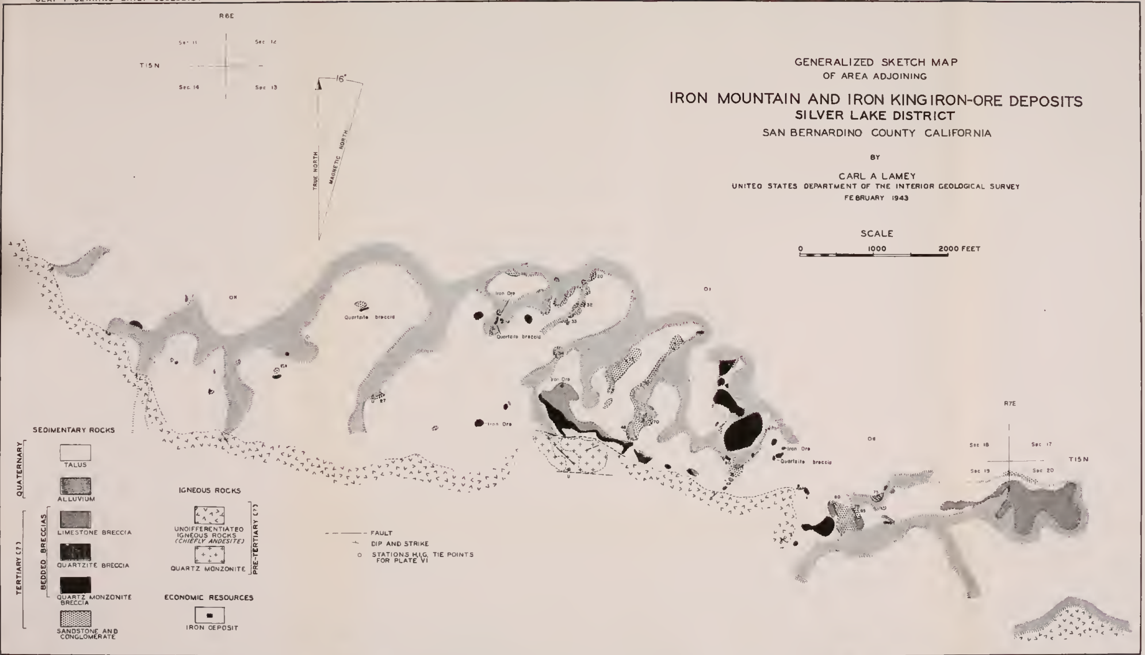


FIG. 17. Map showing location of claims, Iron Mountain and Iron King iron-ore deposits, Silver Lake district, San Bernardino County.

Hew[illegible] the Mohave Desert, California: Nat. Acad. Sci. Proc., vol. 14, no. 1, pp. 7-12, 1928.


GENERALIZED SKETCH MAP
OF AREA ADJOINING
IRON MOUNTAIN AND IRON KING IRON-ORE DEPOSITS
SILVER LAKE DISTRICT
SAN BERNARDINO COUNTY CALIFORNIA
BY
CARL A LAMEY
UNITED STATES DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY
FEBRUARY 1943
SCALE
0
1000
2000 FEET
R6E
T15N
Sec 14
Sec 13
16°
TRUE NORTH
MAGNETIC NORTH
R7E
Sec 18
Sec 17
Sec 19
Sec 20
T15N
Iron Ore
Quartzite breccia
SEDIMENTARY ROCKS
QUATERNARY
TALUS
ALLUVIUM
TERTIARY (?)
BEDDED BRECCIAS
LIMESTONE BRECCIA
QUARTZITE BRECCIA
QUARTZ MONZONITE BRECCIA
SANDSTONE AND CONGLOMERATE
IGNEOUS ROCKS
UNDIFFERENTIATED IGNEOUS ROCKS (CHIEFLY ANDESITE)
QUARTZ MONZONITE
PRE-TERTIARY (?)
ECONOMIC RESOURCES
IRON DEPOSIT
FAULT
DIP AND STRIKE
STATIONS H.I.G. TIE POINTS FOR PLATE VI

GEOLOGY

Rock Units

The sedimentary rocks exposed in the area are (1) sandstone and conglomerate, hereafter referred to as sandstone; (2) limestone and dolomite breccia containing lenses of igneous rock breccia and iron ore, hereafter referred to as limestone breccia; and (3) alluvium. The igneous rocks, as identified megascopically, are chiefly quartz monzonite, hornblende andesite, and diorite, with lesser amounts of rhyolite and amygdaloidal basalt.

General Relations

The ages of the rocks are not definitely known. The sandstone which underlies the ore-bearing limestone breccia has been dated tentatively as middle Tertiary.[1] The limestone breccia is lithologically similar to breccias in nearby areas that have been shown to be of Tertiary age.[2]

The igneous rocks are thought to be older than the sedimentary rocks, but that is not quite certain, because the contact between igneous and sedimentary rocks is faulted wherever exposed. The quartz monzonite is cut by the diorite and hence is the older of the two; the relative ages of the other igneous rocks have not been established.

In topographic expression, the chief rock units present characteristic differences. The sedimentary rocks form the lower ridges and make up the greater part of the surface exposures. Most of these low ridges are capped by limestone breccia or iron ore, and the lower slopes at many places are sandstone (see Pls. VI and VII), which also forms most of the few outcrops in the basins and valleys that do not have continuous floors of alluvium. The higher ridges to the southwest and west are composed of igneous rocks.

Description of Formations

Sandstone. The sandstone is dominantly red but partly light gray. At Iron Mountain the sandstone formation is composed of well-indurated sand and gravel beds ranging in thickness from a few inches to at least 6 feet. Some beds consist of fine sand containing silt, and others of coarse, pebbly, feldspathic sandstone. The gravel beds consist dominantly of rounded to subangular pebbles, cobbles, and small boulders, but in some of the southern exposures boulders 5 feet or more in diameter may be seen. The most characteristic pebbles are spheroidal, with longest diameter between 1 inch and 3 inches; they consist chiefly of igneous and metamorphic rocks, but partly of limestone or dolomite. The igneous and metamorphic rocks are of widely different kinds; among the more conspicuous is a red andesite containing prominent white phenocrysts of plagioclase. The limestone pebbles are mostly dark gray to nearly black, or banded in gray and white. Some of them contain foraminifera, fragments of crinoid stems and possibly also brachiopods and bryozoans. The foraminifera are Fusulinidae that belong to the genera *Schwagerina*, *Schwagerina?*,

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[1] Hewett, D. F., and others, op. cit.

[2] Henshaw, P. C., A Tertiary mammalian fauna from the Avawatz Mountains, San Bernardino County, California: Carnegie Inst. Washington Pub. 514, pp. 1-30, 1939.

Hewett, D. F., Late Tertiary thrust faults in the Mohave Desert, California: Nat. Acad. Sci. Proc., vol. 14, no. 1, pp. 7-12, 1928.

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Hewett, D. F., Late Tertiary thrust faults in the Mohave Desert, California: Nat. Acad. Sci. Proc., vol. 14, no. 1, pp. 7-12, 1928.

and *Pseudoschwagerina*[3], an assemblage characteristic of and restricted to the Wolfcamp series (Permian or Carboniferous).

In the area between Iron Mountain and Iron King the sandstone shows considerable variation; south and west of the road (Pl. VI) it is mostly reddish, north and east of the road mostly gray. In some places the gray beds are silty and argillaceous; in other places, along faults, they are gypsiferous. An unusual assemblage, seen only in a single exposure southwest of the road, consists of brown sandstone and white marl or chalk—the latter containing layers and nodules of chert—and gray argillaceous material. The calcareous beds and the chert contain many small gastropods, perhaps Tertiary fresh-water forms; most of these are high-spired. White beds of volcanic ash exposed north of the road, opposite Iron King, may be part of the sandstone, but their relationships are obscured by a fault. Throughout the area between Iron Mountain and Iron King the conglomerate beds contain large boulders and angular blocks. At Iron King both red and gray sandstone are present, and the material in the conglomerate ranges from well-rounded pebbles and cobbles to large angular blocks.

Within the area mapped, only the uppermost 50 feet of the sandstone is exposed in a continuous section. Time was not available for studying this formation except at the places where it was encountered during the mapping of the iron-ore deposits, but an attempt was made to obtain some information regarding lower horizons that might be exposed along faults.

Traverses northeast from Iron Mountain and Iron King disclosed little regarding these lower horizons. Northeast of Iron Mountain the characteristic red beds of the sandstone are repeated again and again by faults, and they finally disappear along a large thrust fault, giving way to outcrops of gray sandstone interbedded with fanglomerate. Much of this sandstone is feldspathic but some of it is gypsiferous, argillaceous, or calcareous. Some of it is ripple-marked and much of it is cross-bedded. Northeast of Iron King, beneath the limestone breccia, are large exposures of sandstone, some beds of which resemble that exposed at Iron King.

The geologic structure northeast of Iron Mountain and Iron King is so complex that a detailed regional study of stratigraphic relations could not be made in the time available. At least a part of the sandstone northeast of Iron King is thought to be the same as that exposed at Iron King and Iron Mountain, but thrust faulting has there brought similar beds into contact with one another. In order to determine the stratigraphic relations satisfactorily, it would probably be necessary to make a detailed study of the entire surrounding area.

Limestone Breccia. Only the lowermost 200 feet of the limestone breccia is exposed. The formation is gray to light brown. It is apparently made up of a series of lenses and consists chiefly of limestone fragments. These pieces of limestone range in length from a quarter of an inch to 30 feet or more, but fragments 2 to 20 inches across predominate; most of them are angular, some are slightly rounded. In general the formation is tightly cemented with calcium carbonate and shows little or no bedding.

[3] Henbest, Lloyd G., written communication.

Intercalated with the limestone breccia are lenses of breccia that consist of igneous and metamorphic rocks. As a rule each lens consists chiefly of a single type of rock, and igneous rocks predominate. The most characteristic lenses consist of gray to dull-green and brown andesite or basalt, light-tan rhyolite, and slightly green to red or lilac quartz monzonite. The most abundant of the metamorphic rocks are greenish material, which may be a contact phase of the quartz monzonite in the monzonite breccia, and a green to gray rock consisting chiefly of anthophyllite or some other amphibole interwoven with crystallized magnetite.

The lenses of breccia composed of igneous and metamorphic rocks appear to be confined to the lower part of the limestone breccia, and at many places they are associated with iron ore. Such lenses are especially prominent in the vicinity of Iron King, where they form ridges from 30 to 50 feet high. There the dominant rock in these lenses is quartz monzonite, fragments of which attain a length of 5 feet or more.

The iron ore occurs in lenses which are confined to the lower part of the limestone breccia. They are composed chiefly of magnetite but include some hematite and limonite. Some lenses consist of nearly pure, massive iron ore, others are conglomeratic and contain 10 to 50 percent or more of waste rock. The principal rocks enclosed in the iron ore are limestone, some of it partly replaced by magnetite, and metamorphic rock containing some magnetite. Andesite or basalt, rhyolite, and quartz monzonite are closely associated with the iron ore, but as a rule they occur in separate lenses underlying or overlying it.

Alluvium. Much of the alluvium is an unconsolidated mixture of rock fragments and sand, but some of it is well cemented. Possibly the cemented material is older than the unconsolidated alluvium, but there appears to be no adequate basis for separating the two. The thickness of the alluvium is unknown, but in places as much as 20 feet is exposed.

Igneous Rocks. The igneous rocks adjacent to the Iron Mountain deposits consist chiefly of quartz monzonite and hornblende andesite, but they include some diorite, and, farther to the southwest and west, some amygdaloidal basalt and rhyolite.

The monzonite is pink to light green on fresh fractures and becomes light brown to red on weathered surfaces. Much of it is porphyritic, with phenocrysts of pink orthoclase half an inch to an inch long and three-tenths of an inch to half an inch wide, which enclose some quartz. The groundmass is composed of quartz, biotite in crystals up to a quarter of an inch across, orthoclase, and white plagioclase. In places the groundmass of the monzonite is fine grained and has a rhyolitic appearance.

The hornblende andesite varies from reddish to greenish. It is porphyritic, with phenocrysts of white to green plagioclase about two-tenths of an inch long and a quarter as wide, and smaller, less prominent phenocrysts of hornblende, in a dense groundmass. In places this rock exhibits a well-developed flow structure. Near faults the rock has been altered to a greenish material in which the phenocrysts are obscured.

The diorite is gray when fresh and weathers brown. In general it exhibits a medium granitoid texture, but in places its texture resembles that of diabase. Its chief minerals are plagioclase and hornblende. The amygdaloidal basalt is dark gray to dark green. Characteristic minerals in the amygdules are epidote, quartz, chlorite, and jasper. The rhyolite

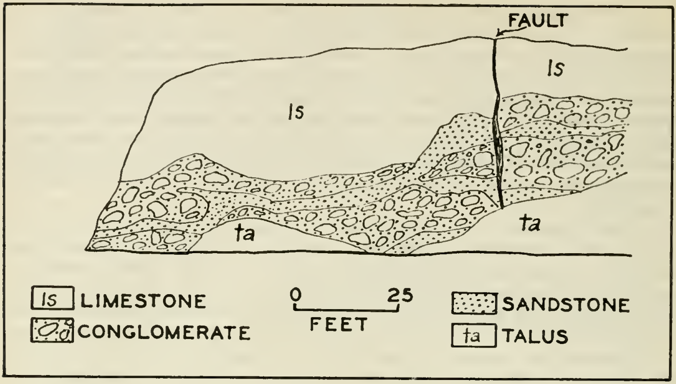


FIG. 18. Sketch of exposure showing bedded limestone breccia, conglomerate, sandstone, and talus. Looking southeast between Iron Mountain and Iron King iron-ore deposits.

is fine grained and is light gray to tan. In some places it has a well-developed flow structure.

Structure

The geologic structure of the Iron Mountain-Iron King area is highly complex and appears to be related to that of the Virgin Spring area in southern Death Valley, about 40 miles to the northwest. There the outstanding structural features are great low-angle Tertiary thrust faults, which have been folded. The folding has been accompanied or followed by large-scale movement on steep faults. In part of the Virgin Spring area the rocks are so intricately broken the disorder is chaotic.[4] Similar complex masses,[5] moreover, have been found in all directions from the Iron Mountain-Iron King area, at distances ranging from 15 to 40 miles. One of those masses contains a pre-Cambrian talc deposit with its associated rocks. Hence it may well be that the ore deposits and associated rocks of the Iron Mountain-Iron King area are part of an enormous thrust block.

Brief study of the small Iron Mountain-Iron King area is not sufficient, however, to show how the area fits into the complex regional picture, nor to unravel all the details of the local structure. These include many folds and faults, and also discordant relations between the sandstone and the overlying limestone breccia that are probably due to an unconformity but may be caused by a low-angle fault.

[4] Noble, L. F., Structural features of the Virgin Spring area, Death Valley, California: Geol. Soc. America Bull., vol. 52, p. 958, 1941.

[5] Noble, L. F., written communication; also op. cit., pp. 994, 996-997.
Hewett, D. F., Late Tertiary thrust faults in the Mohave Desert, California: Nat. Acad. Sci. Proc., vol. 14, no. 1, pp. 7-12, 1928; Geology and ore deposits of the Goodsprings quadrangle, Nevada: U. S. Geol. Survey Prof. Paper 162, pp. 42-55, 1931; (In manuscript) Geology and ore deposits of the Ivanpah quadrangle, Nevada and California: U. S. Geol. Survey.

Discordant Relations

The relations between the sandstone formation and the breccia are obscured by faulting. Although most of the faults are within the sandstone, some of them bring the two rocks into contact. At the few places where an unfaulted contact is exposed, it appears to be an uncomformable one, being irregular and marked by an abrupt change in character of material (see fig. 18). The underlying rock is sandstone or a conglomerate containing rounded fragments of a large variety of igneous and metamorphic rocks. The overlying rock is usually limestone breccia consisting chiefly of angular fragments of limestone. In some places, however, the material immediately overlying the sandstone or conglomerate is breccia consisting of igneous or metamorphic rock, and in some places it is iron ore.

The discordant relations between the limestone breccia and the sandstone might conceivably mean that the breccia was thrust over the sandstone along a flat fault. In the vicinity of Iron King, the coarse fanglomerate facies of the sandstone contains huge blocks of quartz monzonite, and there quartz monzonite lenses are abundant in the limestone breccia. These relations suggest a gradational contact, but it seems unlikely that such a relation exists. At any rate the contact between the limestone breccia and the sandstone is not well enough exposed to warrant a positive conclusion.

Folds

Folds are distinguished with difficulty in the limestone breccia, owing to its massive and lenticular character, but they are much more easily discernible in the sandstone, which was therefore used as a guide for locating folds in the limestone. Owing, however, to the discordance between the two formations, the interpretations thus arrived at were sometimes open to doubt.

At Iron Mountain the prevailing dips are to the southeast or the northeast, though locally the dip is to the west. The inclination is usually between 20° and 40° but locally as steep as 75°. Although the evidence is not clear, it indicates the presence of several anticlines and synclines.

Folds can best be traced in the area between Iron Mountain and Iron King, where exposures of sandstone are numerous. There, as a rule, the anticlines and synclines are asymmetrical and pitch to the southeast, but in a few places they are overturned.

At Iron King the formations are thrown into close folds, which trend nearly east. The principal iron-ore deposits occur in a syncline overturned toward the south. Southward this syncline is succeeded by an overturned anticline, and that by another syncline, possibly also overturned. The prevailing dips are northward and range from 75° to 90°.

Faults

Both normal and reverse faults are found, and most of them have steep dips.

In the immediate vicinity of the ore deposits there are faults of at least four ages, trending in different directions. They appear to have

been formed in this order: (1) faults trending about N. 75° W.; (2) faults trending between north and N. 45° W., many of them about N. 20° W.; (3) faults trending about N. 75° E.; and (4) very recent faults, trending about N. 45° W., which displace the alluvium. Trends vary considerably, and the trace of a fault on a horizontal surface may show a considerable amount of curvature.

The relative direction of movement along faults of different ages is probably not everywhere the same, but the following relations appear to be characteristic: group 1, north side downthrown; group 2, west side downthrown and apparently moved north; group 3, south side downthrown and apparently moved eastward. Where a block has moved down or up between parallel faults, the direction of downthrow on one of the bounding faults is the reverse of that on the other.

The boundary between sedimentary and igneous rocks appears to be everywhere a fault contact; nowhere was it seen to be an intrusive contact or a normal depositional contact. The sedimentary rocks dip away from the igneous rocks, and the dip steepens near the contact, as if the igneous rocks were upthrown. The exposures are poor, however, and the contact is not simple, being apparently marked by faults trending in several directions. On the map, therefore, the contact is not everywhere shown as a fault.

Folds and Faults in Adjoining Areas

Area Northeast of Iron Mountain. Northeast of Iron Mountain the sandstone and the overlying limestone breccia are exposed for 2 or 3 miles. Although the general dip of the beds is to the southeast and the altitude increases to the north, all of the exposures between the limestone breccia and the underlying sandstone are close to the contact, because the formations are repeated by faulting. In this area the sandstone is strikingly red.

About 3 miles northeast of Iron Mountain the red sandstone and the limestone breccia give way, on a fault contact, to a light-gray sandstone, which dips northeast. The gray sandstone apparently was thrust over the red sandstone and limestone breccia from the north along a fault having a dip of about 20° N. Exposures in canyons north of the contact between gray and red sandstone are characterized by great structural confusion; the beds are cut by many faults, and folding is complex. Dips range from horizontal to vertical within short distances. Anticlines and synclines are overturned, and at places they are recumbent. These relations confirm the belief that the contact is a thrust fault. No additional outcrops of red sandstone or limestone breccia were found on a traverse extending for about a mile northward from the fault contact.

The gray sandstone is of various types—feldspathic, argillaceous, gypsiferous, and calcareous—and is interbedded with large lenses of fanglomerate composed chiefly of fragments of igneous rocks. At some places along canyon walls, hills and ridges of igneous rock buried beneath the gray sandstone are partly exposed. In one exposure a conglomerate resting on igneous rocks grades upward into conglomeratic sandstone.

Area Northeast of Iron King. About 2 miles northeast of Iron King, limestone breccia and sandstones crop out. The sandstone, which is well exposed along a deep valley, apparently belongs to the same for-

mation that underlies the limestone breccia at Iron King. It is in large part gray, feldspathic, and gypsiferous, and is associated with lenses of fanglomerate. It has been complexly folded, and the attitude of cross-bedding indicates that some of it, at least, has been overturned. A large block of sandstone containing much volcanic ash has here been thrust from the northeast over a syncline which pitches southeast; the fault plane truncates the steeply dipping beds of the syncline. The thrust faulting may have been followed by folding for the fault surface is very irregular, and its inclination steepens from about 25° to about 75°.

Relation of Ore Deposits to Structural Features

As the ore deposits were formed before the folding and faulting of the strata in which they occur, they have been subjected to deformations that affect both their attitude and their extent. Some of the orebodies have been thinned or terminated by faults, and others have been thickened.

Relation of Structure to Topography

Differential erosion of nonresistant sandstone overlain by resistant limestone breccia has resulted in the formation of anticlinal valleys and synclinal ridges. In some fault blocks, the crests and the gentler eastern or dip slopes of the ridges have been developed on the resistant limestone, whereas the steeper western slopes have been carved from the sandstone.

At many places there are saddles where faults cross ridges. Some of the saddles are in sandstone exposed as a result of the faulting, the limestone breccia forming the main part of the crest on both sides; other saddles, in ridges composed entirely of igneous rock, are due to rapid erosion of sheared material in the fault zone.

ORE DEPOSITS

The iron-ore deposits occur as lenses in the lower part of the limestone breccia. Lenses composed almost entirely of magnetite and hematite grade into lenses containing 50 percent or more of waste. At Iron Mountain the orebodies are all in an area slightly more than a mile long and about half a wide wide, and the larger deposits are confined to a zone about 2,000 feet long and 200 to 800 feet wide. The total of all deposits is about 6,000,000 long tons of good-grade ore that could easily be mined. The Iron King deposits are relatively small, probably containing about 375,000 long tons.

Mineralogy

The mineral composition of the deposits is simple.[6] Magnetite is the dominant ore mineral, but hematite and limonite also are present. The principal gangue mineral is calcite. Near faults the ore contains thin seams of gypsum and a little malachite [$CuCO_3.Cu(OH)_2$] and chrysocolla ($CuSiO_3.2H_2O$), the last two being presumably oxidation products of copper sulphides. At some places anthophyllite (?) [$(Mg,Fe)\ SiO_3$], muscovite [$H_2KAl_3SiO_4)_3$], and perhaps other silicates, are associated with the ore minerals. An interesting feature

[6] Minerals were identified megascopically only.

FIG. 19. View northeastward over the northern iron-ore bodies of Iron Mountain, Silver Lake district.

is the occurrence of magnetite in well-formed dodecahedrons, some of them nearly an inch across, associated with coarsely crystalline calcite or with anthophyllite(?) and actinolite. This association indicates that the material was derived from a contact-metamorphic deposit.

Occurrence

The two chief types of ore consist respectively of: (1) solid, massive magnetite and hematite; and (2) conglomeratic magnetite, hematite, and limonite. The massive ore is relatively free from included rock, but the conglomeratic ore contains, in varying proportions, igneous and metamorphic rocks and partly replaced limestone.

The lenticular bodies of ore are probably confined to the lower 100 feet of the limestone breccia. At some places they rest directly on the underlying sandstone; at others they are separated from it by breccia, the exact thickness of which is not known but is probably between 20 and 50 feet. There is some indication that the larger orebodies rest directly on the sandstone. It is difficult to measure the ore lenses, because of the massive character of the ore and of the limestone breccia together with structural complexities. Apparently, however, the lenses range in length from 50 to 1,000 feet, in width from 20 feet to several hundred feet, and in thickness from a few feet to 100 feet or more.

Distribution

Iron Mountain Deposits. The Iron Mountain deposits are in two principal areas, the one containing the larger reserves to the south, and the one containing the smaller reserves to the north of a road that passes along a valley (Pls. VI and VII). Much of the ore in the northern area is massive, whereas much of that in the southern area is conglomeratic. The two areas are probably separated by a fault.

Outside these two principal areas are scattered orebodies that lie chiefly to the north. These bodies range in size from 50 by 10 feet to 200 by 70 feet (Pls. VI and VII). West of the southern area, also, are small patches of ore at the edge of a valley that follows the southwest side of a mass of andesite.

Outside of the area mapped, to the east and northeast, are a few isolated orebodies. The only one that contains enough ore to be minable lies about 2,000 feet N. 40° E. of the northern end of the mapped area; it is 220 feet long and 35 feet wide. The occurrence and association of the ore in this body are the same as at Iron Mountain.

Iron King Deposits. The Iron King deposits lie chiefly on the south side of a ridge, near its crest (Pl. VI). They consist partly of low-grade ore containing much waste, and partly of high-grade ore. The boundary between these two types approximately coincides with a prominent fault saddle (Pl. VI), east of which the deposits are mostly of low grade. The largest body is on the highest point of the ridge, slightly west of the saddle. The ore beds dip 75° to 90° N.

Origin

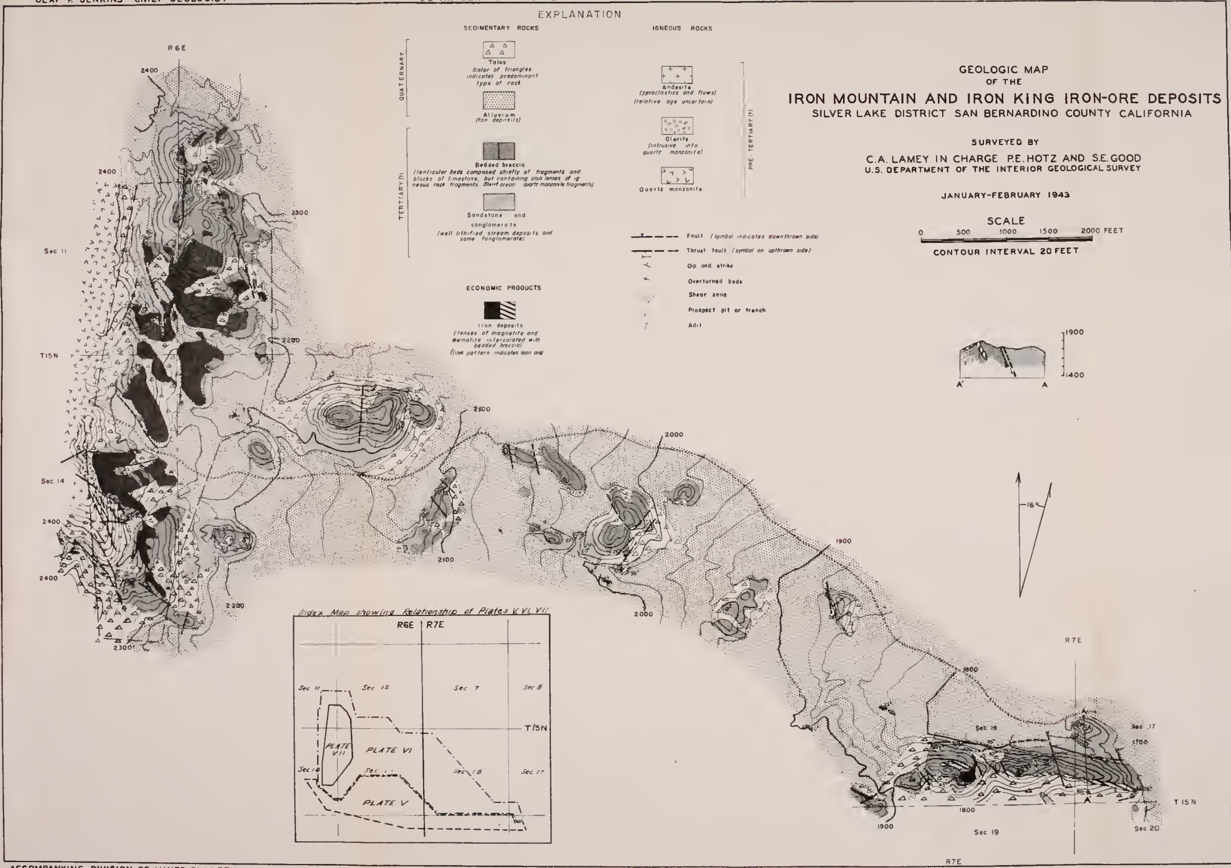
Two widely different agencies have been concerned in the formation of the Iron Mountain and Iron King ore deposits. The large, well-developed crystals of magnetite, associated with coarsely crystal-

line calcite, with silicates such as anthophyllite and actinolite, with contact-metamorphic rock, and with limestone partly replaced by magnetite, are typical of contact-metamorphic replacement bodies. In its present state, however, the ore does not constitute such bodies, for it is fragmental and is intercalated with limestone breccia. The material composing the deposit came from a contact-metamorphic body, but it has been transported, and the source of the material and the manner in which it acquired its present character and reached its present situation are obscure.

It appears likely that a limestone, possibly interbedded with quartzite—for a little quartzite breccia is associated with the ore—was invaded by intrusive magma, and that the ore was formed near the intrusive contact. The intrusive rock formed by this magma is believed to be the quartz monzonite composing the monzonite breccia. In a part of the area this rock is closely associated with the ore, but a fact even more significant is that some blocks of quartz monzonite grade into a contact-metamorphic rock containing magnetite, and such rock is in some places associated with the ore.

The iron ore attained its present character and position in one of two ways. It may have accumulated as talus near the base of a steep fault scarp, and the rocks in place from which the talus was derived were afterward wholly or almost wholly removed by erosion. It seems more likely, however, in view of the prevalence of thrust faulting in the region, that the ore was brought to its present position by one or more thrust faults. On this hypothesis the bedded character of the deposits can be explained by supposing that they were first deposited in the form of beds, perhaps as fanglomerate or talus, and that they were then transported bodily by the thrust faulting, being extensively brecciated in the process but still retaining their bedded character. If the deposits were transported in this fashion, the limestone breccia and underlying sandstone were thrust over the igneous complex.

Quartz monzonite in place, separated from the sedimentary rocks by a fault, crops out west of Iron Mountain (Pl. VI), but it appears to be different from the rock in the quartz monzonite breccia that is associated at Iron Mountain with the ore and limestone, and, though each may represent a different facies of the same magma, the difference indicates that the breccia was not derived from the rock in place. Quartz monzonite also crops out south of Iron King (Pl. V), and near Iron King large masses of quartz monzonite breccia intercalated with limestone breccia are exposed within 50 feet of intrusive quartz monzonite (see Pl. V). A fault separates the monzonite in place from the monzonite breccia, and they differ materially in character: The intrusive rock is pink to tan and contains pink to flesh-colored orthoclase phenocrysts, whereas the monzonite of the breccia is mottled with large red or lilac orthoclase phenocrysts and contains more quartz. At other places south of Iron King, quartz monzonite breccia crops out close to andesite and other igneous rocks (Pl. V), from which it is separated by a fault. The differences between the monzonite in the breccias and that in the igneous mass southwest and west of the iron-ore deposits indicate that the breccias were not derived from the monzonite in this igneous mass. Brief exploration of the igneous masses in the area failed to disclose outcrops of


GEOLOGIC MAP
OF THE
IRON MOUNTAIN AND IRON KING IRON-ORE DEPOSITS
SILVER LAKE DISTRICT SAN BERNARDINO COUNTY CALIFORNIA
SURVEYED BY
C.A. LAMEY IN CHARGE P.E. HOTZ AND S.E. GOOD
U.S. DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY
JANUARY-FEBRUARY 1943
SCALE
0 500 1000 1500 2000 FEET
CONTOUR INTERVAL 20 FEET
EXPLANATION
SEDIMENTARY ROCKS
IGNEOUS ROCKS
QUATERNARY
Talus
(color of triangles indicates predominant type of rock)
Alluvium
(fan deposits)
TERTIARY (?)
Bedded breccia
(lenticular beds composed chiefly of fragments and blocks of limestone, but containing also lenses of igneous rock fragments. Stant areas: quartz monzonite fragments)
Sandstone and conglomerate
(well lithified stream deposits and some fanglomerate)
Andesite
(pyroclastics and flows)
(relative age uncertain)
PRE-TERTIARY (?)
Diorite
(intrusive into quartz monzonite)
Quartz monzonite
ECONOMIC PRODUCTS
Iron deposits
(lenses of magnetite and hematite intercalated with bedded breccia)
(line pattern indicates lean ore)
Fault (symbol indicates downthrown side)
Thrust fault (symbol on upthrown side)
Dip and strike
Overturned beds
Shear zone
Prospect pit or trench
Adit
R6E
R7E
T15N
Sec 11
Sec 14
Sec 17
Sec 18
Sec 19
Sec 20
2400
2300
2200
2100
2000
1900
1800
1700
16°
A
A'
1900
1400
Index Map showing Relationship of Plates V, VI, VII
R6E
R7E
Sec 11
Sec 12
Sec 7
Sec 8
T15N
PLATE VII
PLATE VI
PLATE V
Sec 14
Sec 13
Sec 18
Sec 17

quartz monzonite identical with the rock in the breccia, or remnants of a contact-metamorphic orebody.

Search for the source of the deposits involves a search for remnants of iron ore in place, and for remnants, in place, of the rocks with which it was genetically associated—for limestone, for quartz monzonite and other igneous rocks, and for metamorphic rocks, all similar to the corresponding rocks in the breccias now associated with the iron ore. If rocks of any one of these kinds were found, they would probably be in association with rocks of the other kinds, perhaps with all of them. It is possible, indeed, on either of the hypotheses just outlined, that the source rocks might all have been eroded away, but on neither hypothesis does that seem probable.

Some remnants of quartz monzonite, especially, would be likely still to remain in place. No such remnant, however, has been identified.

The source of the limestone in the breccia also is obscure. The mountain mass adjacent to the deposits consists chiefly of igneous rocks associated with metamorphics. North of Iron Mountain the limestone breccia ends abruptly along a large fault, and the area beyond the fault is underlain by intricately folded sandstone, which appears to rest upon igneous rocks. South of Iron King igneous and metamorphic rocks are exposed. East of Iron King there are no outcrops for about 5 miles, and the first exposures encountered consist of igneous rocks. Marble crops out near by, but it is different from that exposed at the iron-ore deposits.

The source of the deposits thus remains problematical; it may lie outside the area examined.

ORE RESERVES

The Iron Mountain deposits are estimated to contain about 6,000,000 long tons of good, easily mined ore and the Iron King deposits about 375,000 long tons.

The deposits were sampled by the Kaiser Company, Inc., and the following summary of their analyses was kindly released for publication.

Composition of samples collected and analyzed by the Kaiser Company, Inc., Iron Mountain iron-ore deposits, Silver Lake District, San Bernardino County, California

Description	Percent				
	Fe	P	SiO_2	S	CaO
Average of 9 samples	60.0	0.052	6.9	0.099	4.2
Average of 11 samples	54.4	0.045	6.1	0.034	7.65

The U. S. Bureau of Mines reports an average iron content of 54 percent.[7]

[7] Summary of Bureau of Mines exploration projects on deposits of raw material resources for steel production: U. S. Bureau of Mines Report of Investigations No. 3801, pp. 7 and 10, 1945.

Iron Mountain[8]

The Iron Mountain orebodies consist of irregularly tabular masses of magnetite fault breccia intercalated with dolomite breccia, andesite breccia, and complexly mixed breccia (Pl. VII). The contacts between the breccia types are very low-angle faults. The irregular shape and distribution of these orebodies made accurate tonnage estimates difficult. It was possible, however, to determine the general shape and thickness of most of the orebodies and, with the additional data from 11 U. S. Bureau of Mines diamond-drill holes, a reserve figure was reached that probably approaches the actual reserves. In all cases the calculations were conservative, and unless considerable evidence supported an extension, the ore was considered to project only a very limited distance beyond actual outcrop boundaries.

The accuracy of the calculations is affected not only by the irregular lateral variation of the orebodies, but also by the layers of other breccia types faulted into the ore. Many of these breccia layers as shown by sections C-C′, D-D′, E-E′, H-H′, and J-J′ (Pl. VII) do not crop out, and without drill-hole control they could not have been accounted for. Even when a concealed layer of waste rock is discovered by the drill, the problem of its lateral extent remains.

In computing the reserves, a tonnage factor of 10 cubic feet of ore to a long ton was used. Each individual deposit was computed separately by calculating the volume from an isopachous map based on the interpreted thicknesses from a series of cross sections.

Indicated Ore. In the area south of the road the indicated ore reserves were calculated to be 3,300,000 long tons. Sections J-J′ and K-K′ show the inferred relationships of these orebodies. A drill hole in the orebody shown in K-K′ would possibly considerably alter this figure by changing the thickness from that inferred or by discovering masses of other breccia types within the ore.

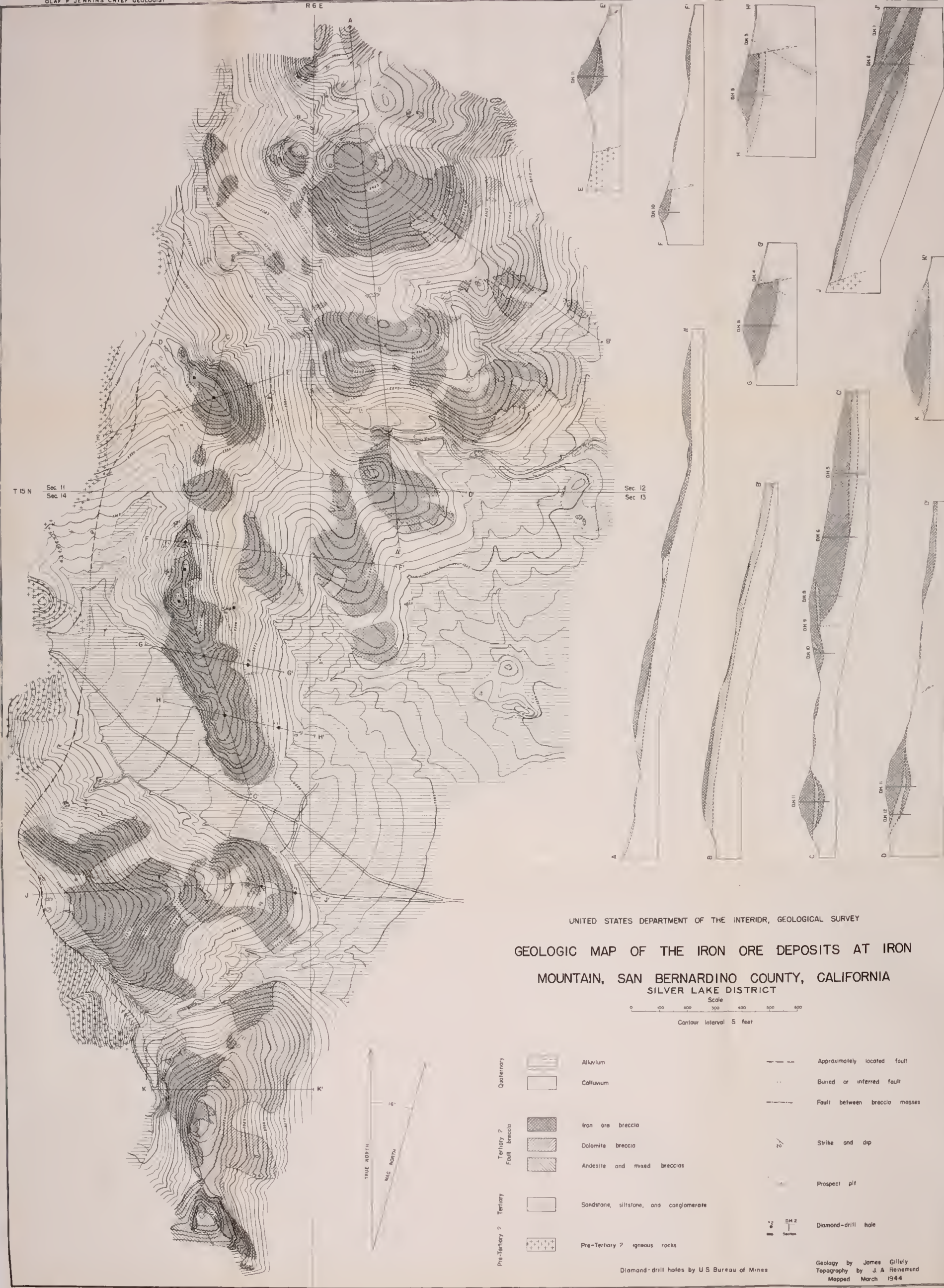
North of the road 1,875,000 long tons of indicated ore reserves were calculated. Two of the larger orebodies were drilled by the U. S. Bureau of Mines and the resulting information permitted relatively accurate tonnage estimates to be made.

The most southerly of the two drilled orebodies had eight holes (nos. 3, 4, 5, 6, 7, 8, 9, and 10) drilled in or around it. Unfortunately the record for hole 7 was not available, and calculations had to be made without it. This orebody is the largest north of the road and contains approximately 970,000 long tons of iron ore. The other orebody drilled was penetrated by two drill holes (nos. 11 and 12). The tonnage calculated here was 168,000 long tons of ore.

The remaining 737,000 long tons of indicated ore comprise the many relatively thin plates of iron-ore breccia that cover a considerable area north of the road. This last figure is probably somewhat in error as there was very little control on the bottoms of these orebodies. As shown by the drilled orebodies, irregularity is to be expected.

Inferred Ore. In addition to the indicated ore, 1,000,000 long tons of iron ore are inferred to be present in this area. The greater part of this, perhaps 700,000 tons, is under the alluvial cover adjacent to the

[8] Data on Iron Mountain iron-ore reserves are contributed by Thomas A. Steven, Geologist, Geological Survey, U. S. Department of the Interior. His estimates are based on geologic work by James Gilluly.



UNITED STATES DEPARTMENT OF THE INTERIOR, GEOLOGICAL SURVEY

GEOLOGIC MAP OF THE IRON ORE DEPOSITS AT IRON MOUNTAIN, SAN BERNARDINO COUNTY, CALIFORNIA

SILVER LAKE DISTRICT

Scale

0 100 200 300 400 500 600

Contour interval 5 feet

Quaternary: Alluvium; Colluvium

Tertiary ? Fault breccia: Iron ore breccia; Dolomite breccia; Andesite and mixed breccias

Tertiary: Sandstone, siltstone, and conglomerate

Pre-Tertiary ?: Pre-Tertiary ? igneous rocks

Approximately located fault

Buried or inferred fault

Fault between breccia masses

Strike and dip

Prospect pit

Diamond-drill hole (DH 2; Map, Section)

Diamond-drill holes by U S Bureau of Mines

Geology by James Gilluly
Topography by J. A. Reinemund
Mapped March 1944

orebodies penetrated by drill holes 1 and 2 and drill holes 3 to 10. As seen from sections C-C′ and J-J′ appreciable thicknesses of iron ore project out under the alluvium.

Another area of inferred ore is that east of the fault shown near the eastern end of section E-E′. The pit along the fault south of the section shows iron ore faulted against conglomerate. The thickness of this iron ore is not known, so no tonnage could be considered as indicated.

Other ore is inferred to be present as thin layers beneath colluvial cover in the northwestern part of the mapped area. The tonnage here is probably small.

Summary of Iron Mountain Reserves

	Indicated ore (long tons)	*Inferred ore (long tons)*
South of road	3,300,000	--------
North of road	1,875,000	--------
Total	5,175,000	1,000,000

Iron King

Ore reserves in the Iron King deposits are difficult to estimate because of the complex geologic structure. Assuming a tonnage factor of 10 and a depth of 100 feet, the reserve ore in the high-grade deposit on the prominent peak west of the saddle is estimated to be about 375,000 long tons of ore. The low-grade ore contains so much waste that it could not under any circumstances be regarded as potential reserve material.

CONDITIONS AFFECTING MINING

Iron Mountain Deposits

Mining of the Iron Mountain deposits would be hampered by lack of water and distance from the railroad. The ore is easily accessible along moderately sloping hillsides, and much of it has practically no overburden, though some of it is covered by 4 or 5 feet of iron-bearing talus or by 2 to 15 feet of alluvium. If water were available, the ore in talus could be recovered by washing. Roads could be built easily and cheaply to almost all the deposits, and there are good sites for buildings and dumps.

Water for domestic use is available in a well at Silver Lake but that hamlet lies 1,400 to 1,500 feet lower than the deposits. Additional water, at a higher level, might be obtained by drilling a well in the alluvial slope west of the mountains that adjoin the area on the west and southwest. The head of this alluvial slope is along the southwest base of the Avawatz Mountains, at an altitude of 4,000 feet, and its foot is about 3 miles northwest of Red Pass, at an altitude of 2,000 feet.[9] The fan is from 2 to 3 miles wide and about 10 miles long. It is bordered on the north, west, and east by higher areas, so that all drainage should be to the south. Hence water might be ponded against the igneous rocks a few miles west of the Iron Mountain deposits, and if so ponded, could be piped through the low pass occupied by the road.

[9] Topographic map, Avawatz Mountains quadrangle, California: U. S. Geol. Survey, 1933, reprinted 1939.

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Water for domestic use is available in a well at Silver Lake but that hamlet lies 1,400 to 1,500 feet lower than the deposits. Additional water, at a higher level, might be obtained by drilling a well in the alluvial slope west of the mountains that adjoin the area on the west and southwest. The head of this alluvial slope is along the southwest base of the Avawatz Mountains, at an altitude of 4,000 feet, and its foot is about 3 miles northwest of Red Pass, at an altitude of 2,000 feet.[9] The fan is from 2 to 3 miles wide and about 10 miles long. It is bordered on the north, west, and east by higher areas, so that all drainage should be to the south. Hence water might be ponded against the igneous rocks a few miles west of the Iron Mountain deposits, and if so ponded, could be piped through the low pass occupied by the road.

[9] Topographic map, Avawatz Mountains quadrangle, California: U. S. Geol. Survey, 1933, reprinted 1939.

The Tonopah and Tidewater Railroad formerly had a station at Silver Lake, but the rails were recently removed from the road bed. The most accessible railway station is now at Dunn, on the Union Pacific Railroad, to which the ore would have to be hauled by truck for a distance of 47 miles. All but 12 miles of this distance is over paved highway. The 12 miles of unpaved road, which lies between the deposits and Silver Lake, is in poor condition, except for a few miles of private road controlled by the California Bureau of Power and Light; all of it, however, could be put in good condition at moderate cost. In its course from the deposits to Silver Lake, the road rises for a few hundred feet on grades of 15 to 45 percent, but elsewhere it continually descends, with an average grade of 3.7 percent.

Because of scarcity of water and the long haul by truck, the deposits are workable at emergency prices only.

Iron King Deposits

Scarcity of water and distance from the railroad must likewise be a handicap in mining of the Iron King deposits; and there, moreover, the one workable orebody is slightly less accessible from the present road than the Iron Mountain deposits.

STATE OF CALIFORNIA
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WARREN T. HANNUM, Director

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SAN FRANCISCO] BULLETIN No. 129—PART D [JUNE 1945

Iron Resources of California
Bulletin No. 129

PART D

Old Dad Mountain Iron-Ore Deposit San Bernardino County, California

By CARL A. LAMEY
Geological Survey, U. S. Department of the Interior

Issued by the
STATE DIVISION OF MINES

OLD DAD MOUNTAIN IRON-ORE DEPOSIT, SAN BERNARDINO COUNTY, CALIFORNIA *

By Carl A. Lamey **

United States Department of the Interior, Geological Survey

OUTLINE OF REPORT

ABSTRACT

The Old Dad Mountain iron-ore deposit is in the Mojave Desert, about 16 miles southeast of Baker, San Bernardino County, California. A reserve of between 400,000 and 500,000 long tons of ore, minable at emergency prices only, is indicated.

Quartzite and limestone are intruded by monzonite. Ore is present in the limestone, near the contact with the monzonite. Both the quartzite and the limestone are folded, metamorphosed, fractured, and mashed. All rocks exposed are cut by numerous faults. The age of the rocks is not definitely known, but both pre-Cambrian and Paleozoic rocks may be present.

INTRODUCTION

The Old Dad Mountain iron-ore deposit is about 16 miles southeast of Baker, San Bernardino County, California, in the Mojave Desert (fig. 20). It is in the NE¼ T. 12 N., R. 10 E., probably in sec. 13 or sec. 14. It is reached by a dirt road from Baker.

The area is characterized by mountain masses rising a few hundred to about 3,000 feet above the floor of the desert. The highest mass is Old Dad Mountain, with an altitude of 4,275 feet. It rises about 3,000 feet above the desert floor, and forms the central peak of a mountain range about 12 miles long. About 4 miles west of the crest of Old Dad Mountain the topography is diversified by the Devils Playground, a sandy part of the desert characterized by dunes.

The orebodies are along the northwest side of Old Dad Mountain at altitudes ranging from 2,440 to 2,680 feet. They are between 1,500 and 1,800 feet above the Mojave River drainage basin.

Transportation of ore would require truck haulage over 10 miles of dirt road to Sands, a station on the Union Pacific Railroad.

Water is available at Baker, and also at some of the railroad stations south of Old Dad Mountain. However, all of those places are about 1,500 feet lower than the orebodies.

* Published by permission of the Director, Geological Survey, U. S. Department of the Interior. Manuscript submitted for publication September 28, 1944.

** Geologist, Geological Survey, U. S. Department of the Interior.

Exploration work consists of two adits, one 200 feet long, the other 40 feet long, and a few pits. No ore has been produced. The deposit is owned by Charles Reat, Baker, California, and Louis Meyer, Barstow, California.

The deposit was examined on February 1, 4, and 5 by Carl A. Lamey, Preston E. Hotz, and Stanley E. Good. Mapping was done by means of plane table and telescopic alidade. The altitude was established by aneroid barometer.

GEOLOGY

Rock Units

The chief rocks associated with the ore deposits are (1) limestone or dolomite, (2) quartzite, (3) monzonite, and (4) alluvium. The limestone and quartzite are interbedded in part of the area, and both of them are cut by monzonite. The age of the rocks is unknown, but both pre-Cambrian and Paleozoic units may be present.

Either there are two limestones present or two distinct facies of a single formation separated by a fault. One of these limestones is exposed along the higher slopes and in the mountain mass southeast of the ore deposit, and the other one crops out in close association

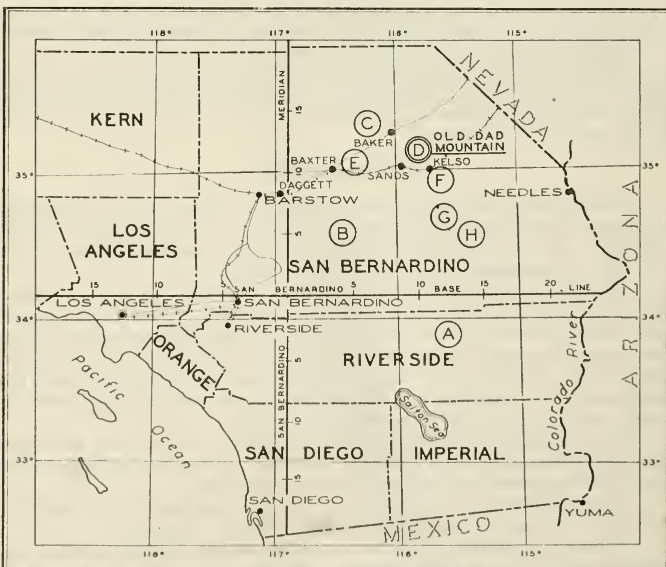

FIG. 20. Index map of southern California iron-ore deposits showing: (A) Eagle Mountains; (B) Iron Mountain (Lava Bed); (C) Iron Mountain (Silver Lake); (D) OLD DAD MOUNTAIN, described in this report; (E) Cave Canyon; (F) Vulcan; (G) Iron Hat; (H) Ship Mountains.

with the iron ore. The former limestone is relatively little altered, whereas the chief characteristic of the limestone, quartzite, and monzonite closely associated with the iron ore is extreme alteration.

The limestone composing the mountain mass southeast of the ore deposits is gray to brown. Much of it is well stratified and contains chert nodules, lenses, and beds. Some of it is a limestone breccia composed of angular fragments varying in size from less than an inch to 1 foot or more. It is relatively unaltered, and is separated from the iron-ore deposit by a fault (fig. 21).

The limestone closely associated with the iron ore is much altered. It varies from light brown to dark brown, and grades into rock partly replaced by magnetite. Most of it is much sheared. Only small masses of it are present.

The quartzite varies from vitreous to argillaceous or sericitic. It is gray to slightly brown. Most of it is much altered and grades into a greenish metamorphic rock intermediate between quartzite and monzonite.

Both the quartzite and the limestone associated with the ore deposits are so much metamorphosed as a result of contact action and shearing that it was impractical to differentiate between them in much of the area. Hence large exposures are placed together on the map as metamorphosed quartzite and limestone (fig. 21). Undoubtedly monzonite is included with these metamorphosed sediments.

Much of the monzonite is sheared, and it is contaminated by its intrusion into quartzite. Unaltered exposures are rare. The least altered rock is somewhat green to gray, is moderately granitoid, and contains orthoclase, plagioclase, and biotite. Near the quartzite it gradually passes into the greenish rock referred to above that is intermediate between monzonite and quartzite. At many places it is difficult or impossible to determine whether a rock is altered monzonite or altered quartzite.

The alluvium is composed of sand and rock debris. It mantles the lower slopes only.

Structure

The rocks have been folded, intruded, and faulted. Old Dad Mountain has been described as a remnant of a thrust plate of Carboniferous and other rocks lying on a basement of earlier pre-Cambrian and other rocks.[1]

In general the ore-bearing rocks strike northeast and the dip is either steeply northwest or vertical. The quartzite and limestone, which are closely associated with the ore deposits, were folded and later intruded by monzonite. Faulting certainly occurred after intrusion and development of the ore, and may have occurred prior to intrusion as well. Only the major faults associated with the iron ore are shown on the map (fig. 21). No attempt was made to show the numerous faults that cut the metamorphosed sediments and the monzonite.

[1] Hewett, D. F., Geology and ore deposits of the Ivanpah quadrangle, Nevada and California. U. S. Geol. Survey, in manuscript. Quoted by Noble, L. F., Structural features of the Virgin Spring area, Death Valley, California: Geol. Soc. America Bull., vol. 52, p. 996, 1941. See also Hewett, D. F., Late Tertiary thrust faults in the Mojave Desert: Nat. Acad. Sci. Pro. 14, pp. 7-12, 1928.

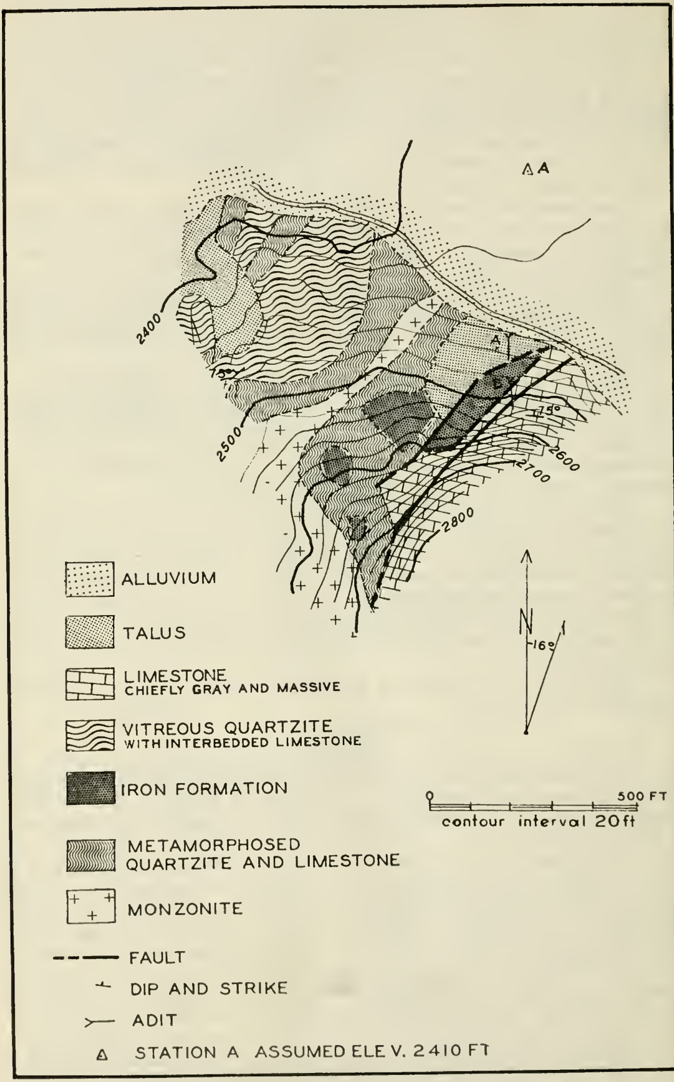

FIG. 21. Geologic and topographic map of the Old Dad Mountain iron-ore deposit, San Bernardino County.

The limestone composing the mountain mass southeast of the ore deposits is separated from them by a large fault that has resulted in the formation of a conspicuous cliff (fig. 21). At the surface this fault appears to be nearly vertical or to dip steeply southeast. It may be the one cutting across the south end of the longer adit (fig. 22). If so, it dips about 70° southeast. However, the dip of the fault may change within short distances and it may become much flatter. The structure of the limestone southeast of this fault apparently differs from that of the adjacent ore-bearing rocks. Locally the limestone dips steeply northward, but it is much less fractured and sheared than the adjacent rocks.

ORE DEPOSITS

Mineralogy and Occurrence

The ore is gray and massive, except where it is sheared. The ore minerals are magnetite and hematite. The chief impurities are calcite, quartz, gypsum, pyrite, chalcopyrite, and possibly pyrrhotite. At some places sulphides compose at least 5 percent of the ore.

The ore is closely associated with monzonite, metamorphosed limestone, and quartzite. It occurs as elongated masses, which have the same general trend as the ore-bearing rocks, and as more or less circular bodies.

Distribution

The Old Dad Mountain deposit consists of two principal orebodies and several minor ones. These bodies are in a zone about 250 feet wide and 700 feet long, the southeastern boundary of which is a large fault (fig. 21). The eastern of the two principal orebodies is elongated parallel to this fault and follows, in a general way, the steep limestone cliff southeast of it. The other principal orebody has a somewhat circular surface outline. It lies west of the elongated one and is separated from it by a fault. Minor orebodies are located southeast of the two principal ones.

In addition to the orebodies forming the major zone, there are a few scattered ore patches in the adjacent area. About 2,300 feet southwest and south of the large circular body there are a few small exposures of ore at altitudes ranging between 3,050 and 3,100 feet. It is possible that larger orebodies may underlie the upper limestone in this vicinity. About a quarter of a mile to the northeast, at the base of an adjacent mountain composed of limestone and various igneous and metamorphic rocks, there is another very small patch of ore. None of the small outlying orebodies examined appears to be important.

Origin

The origin of the orebodies seems to be clear, regardless of the fact that the rocks containing them have been much shattered and mashed. Apparently a formation consisting of quartzite and limestone or dolomite was intruded by monzonite and the ore developed in the limestone. Limestone remnants, partly replaced by magnetite, grade into iron ore. The orebodies, therefore, should be classed as contact-metamorphic replacements.

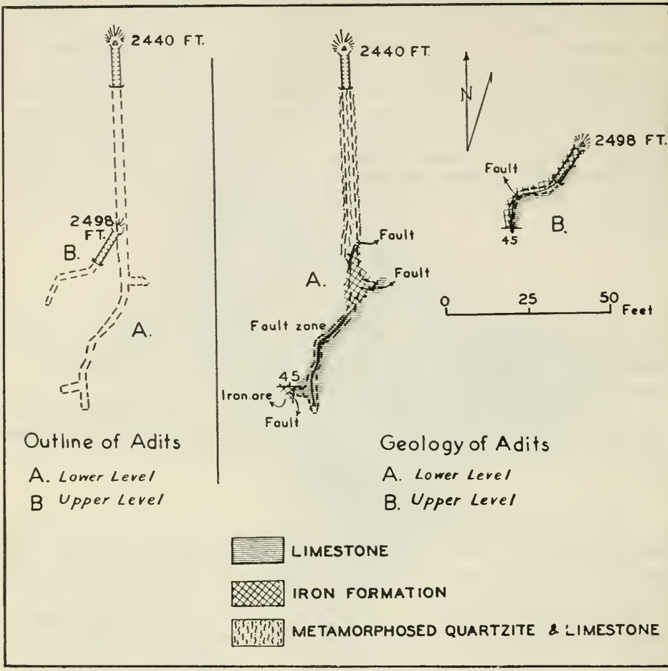

FIG. 22. Map showing geology of adits, Old Dad Mountain iron-ore deposit.

ORE RESERVES

It is estimated that the ore reserves are between 400,000 and 500,000 long tons, minable at emergency prices only. Much of this amount is inferred ore, although two adits indicate that there should be approximately 300,000 long tons of ore in one body.

The easternmost of the two principal orebodies appears to be the larger. It is composed of shattered and sheared ore containing relatively large amounts of sulphides. It is 70 feet wide and is exposed at places throughout a length of 370 feet and a vertical distance of 180 feet. Two adits indicate that the depth of ore may be about 150 feet (fig. 22).

The adjacent western orebody covers a somewhat circular area of about 20,000 square feet. Exposures indicate that it has a depth of about 80 feet. This ore may have a lower sulphur content than the ore of the eastern body.

The amount of waste rock in the orebodies is uncertain. It is estimated to be approximately 15 percent, although it may be greater.

The composition of the ore is indicated by the analyses of two samples collected and analyzed by the Kaiser Company, Inc., which have been courteously released for publication. These follow.

Composition of samples collected and analyzed by the Kaiser Company, Inc., Old Dad Mountain iron-ore deposits, San Bernardino County, California

Per cent						
Fe	*P*	*SiO_2*	*S*	*CaO*	*MgO*	*Al_2O_3*
51.79	0.028	11.65	0.044	5.44	1.71	0.95
57.27	0.032	8.02	0.068	2.81	1.09	0.77

Although it is not shown by the above analyses, field examination indicates that the sulphur content of parts of the ore is likely to be high.

A tabulation of inferred reserves based on the foregoing estimates follows:

Reserves of inferred iron ore, Old Dad Mountain iron-ore deposit, NE ¼ T. 12 N., R. 10 E.

Orebody	*Ore, long tons, according to tonnage factor*	
	10 cu. ft. per long ton	*12 cu. ft. per long ton*
Elongated eastern body	330,000	275,000
Circular western body	133,000	111,000
Small bodies	50,000	42,000
Total, all bodies	513,000	428,000

Some orebodies may possibly be present southwest of these deposits, beneath the upper limestone. If so, the estimated reserves might be increased by several hundred thousand tons.

CONDITIONS AFFECTING MINING

Transportation facilities and lack of water are the chief factors adversely affecting mining, although the high sulphur content of about one-fourth of the ore is objectionable. Transportation of ore would necessitate truck haulage over dirt road for about 10 miles to Sands, a station on the Union Pacific Railroad. Part of this dirt road is controlled by the California Bureau of Power and Light.

Some difficulty might be encountered because of the steep limestone face against which the principal orebody abuts. The ore is separated from the limestone by a fault. If mining is undertaken, some difficulty may be caused by rock falls.

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SAN FRANCISCO] BULLETIN No. 129—PART E [JUNE 1945

Iron Resources of California
Bulletin No. 129

PART E

Cave Canyon Iron-Ore Deposits
San Bernardino County, California

By CARL A. LAMEY
Geological Survey, U. S. Department of the Interior

Issued by the
STATE DIVISION OF MINES

CAVE CANYON IRON-ORE DEPOSITS, SAN BERNARDINO COUNTY, CALIFORNIA *

By Carl A. Lamey **

United States Department of the Interior, Geological Survey

OUTLINE OF REPORT

ABSTRACT

The Cave Canyon iron-ore deposits are in the Mojave Desert, about half a mile north of Baxter, San Bernardino County, California. The deposits are owned by the California Portland Cement Company, Los Angeles, and are being mined in open pits by A. S. Vinnell Company, Alhambra.

The reserves may be as much as 3,500,000 to 4,000,000 long tons of ore, with which much waste rock is associated. Probably not more than 2,500,000 tons of ore are recoverable, and possibly half of this amount could be mined at normal peacetime prices.

The orebodies are steeply inclined lenticular masses. Some are associated with gneissic and possibly also quartzitic rocks, and others are associated with pre-Cambrian limestone or dolomite. A dioritic rock and remnants of partly replaced limestone are constantly present with the ore, indicating that it was formed as a contact-metamorphic replacement of limestone.

Faults, shattered and brecciated zones, and folds are the characteristic structural features of the area.

INTRODUCTION

The Cave Canyon iron-ore deposits are in the Mojave Desert, San Bernardino County, California (fig. 23). They are about half a mile north of Baxter, chiefly in sec. 12, T. 11 N., R. 6 E., S.B. The claims covering the deposits are shown by figure 24.

The deposits are reached by a dirt road connecting with U. S. highway 91 about half a mile east of Cronise Valley. This road crosses part of the bed of the Mojave River, which is usually dry. During and shortly after flood periods, however, the road is nearly or entirely impassable.

* Published by permission of the Director, Geological Survey, U. S. Department of the Interior. Manuscript submitted for publication September 28, 1944.

** Geologist, Geological Survey, U. S. Department of the Interior.

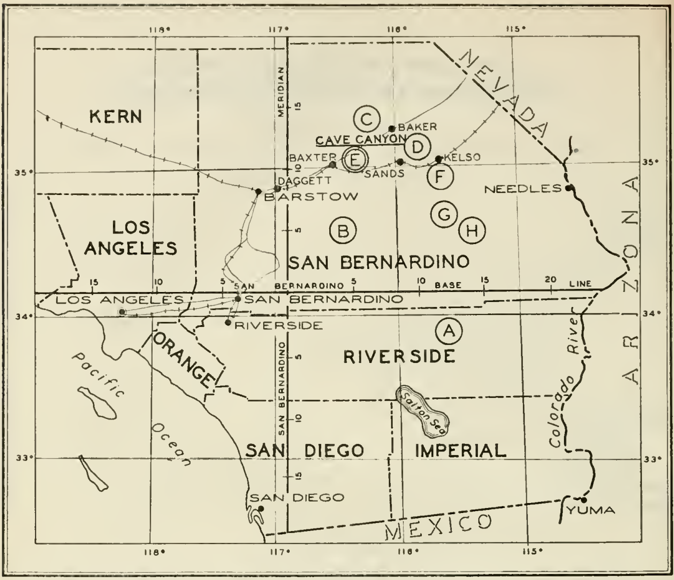


Fig. 23. Index map of southern California iron-ore deposits, showing: (A) Eagle Mountains; (B) Iron Mountain (Lava Bed); (C) Iron Mountain (Silver Lake); (D) Old Dad Mountain; (E) CAVE CANYON, described in this report; (F) Vulcan; (G) Iron Hat; (H) Ship Mountains.

Topographically the area is characterized by ridges trending northeast, with hills interspersed between the ridges. The chief orebodies crop out at altitudes between 1,400 and 1,450 feet, and form a low central ridge that lies between higher ridges to the south and north. Other orebodies are near the foot of the southern ridge, at altitudes between 1,200 and 1,280 feet.

The deposits are owned by the California Portland Cement Company, 601 West Fifth Street, Los Angeles, California, and are being mined in open pits by A. S. Vinnell Company, Alhambra, California. Ore is transported by truck about half a mile to a spur track of the Union Pacific Railroad.

The orebodies have been explored by a number of trenches, adits, and shafts, one of the latter being about 125 feet deep. Most of the adits can be entered, but ladders and timbering in the shafts are not in good condition.

For a number of years the ore has been used in the manufacture of cement.

north by gneissic rocks and to the south by the sandstone-fanglomerate.

[1] Cave Canyon iron mine: California Div. Mines, Min. Abstracts, Iron, p. 26, 1941. Hewett, D. F., Callaghan, Eugene, Moore, B. N., Nolan, T. B., Rubey, W. W., and Schaller, W. T., Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, p. 78, 1936.

GEOLOGIC MAP AND SECTIONS
OF THE

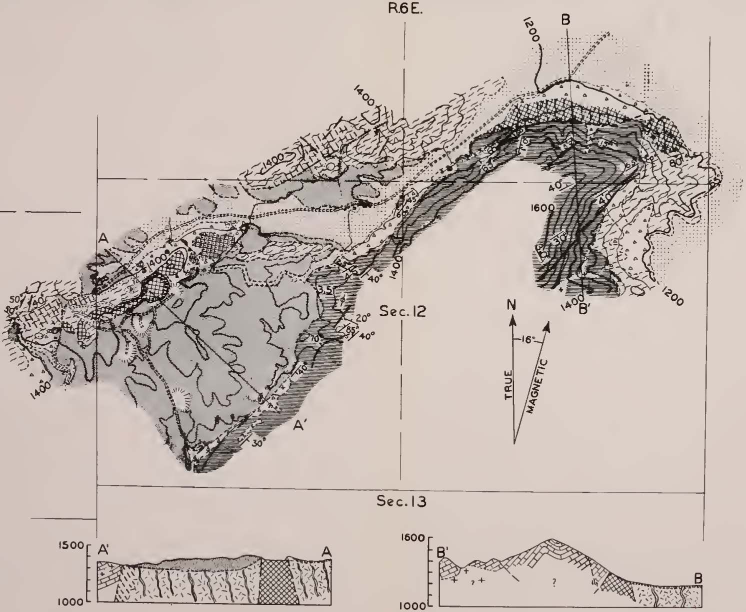
CAVE CANYON IRON-ORE DEPOSITS
BAXTER, SAN BERNARDINO COUNTY, CALIFORNIA

TOPOGRAPHY AND GEOLOGY BY

C.A.LAMEY, IN CHARGE, P.E HOTZ AND S.E.GOOD
UNITED STATES DEPARTMENT OF THE INTERIOR, GEOLOGICAL SURVEY

MARCH 1943

SCALE
0 1000 2000 3000 FT.
CONTOUR INTERVAL 20 FEET



EXPLANATION

SEDIMENTARY ROCKS

ALLUVIUM
(Sand and gravel)

TALUS

FANGLOMERATE
(Lithified alluvial fan material composed of lenticular beds of fragmental rock and sandstone)

CRYSTALLINE LIMESTONE
(White and bluish gray moderately well-bedded crystalline limestone

IGNEOUS ROCKS

DIORITE PORPHYRY
(Green, slightly altered, medium grained porphyritic rock with prominent plagioclase phenacrysts.)

UNDIFFERENTIATED
(Metamorphosed igneous and sedimentary rocks.)

ECONOMIC PRODUCTS

IRON ORE
(Dot on pattern indicates lean ore.)

Areas of possible ore under cover

Fault
Strike and dip of beds
Strike of vertical beds
Strike and dip of schistosity
Crushed zone
Adit

Shaft
Dump

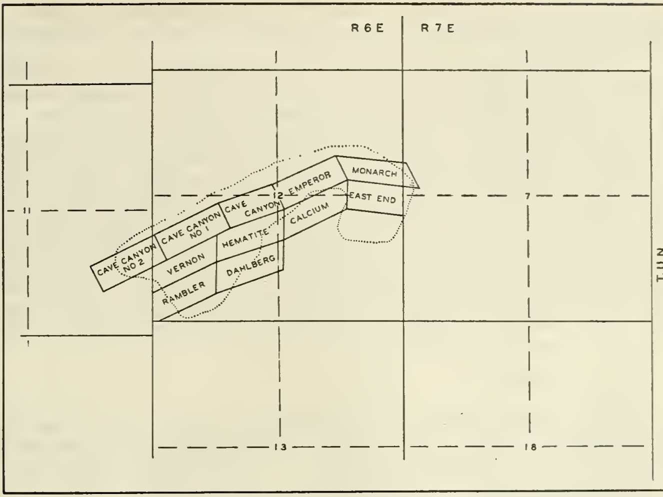


FIG. 24. Claim map, Cave Canyon iron-ore deposits, San Bernardino County. Dotted line indicates position of mapped area.

There is very little published material regarding these deposits.[1]

The deposits were examined and mapped during March 1943, by Carl A. Lamey, Preston E. Hotz, and Stanley E. Good. Mapping was done by means of plane table and telescopic alidade. Elevation was established from U. S. Geological Survey bench mark No. 1421 at Baxter. True north was determined by use of the Baldwin solar chart.

Acknowledgment is due to employees of A. S. Vinnell Company for courtesies extended in the field.

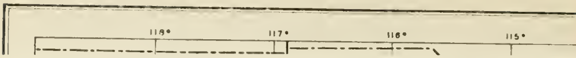
GEOLOGY

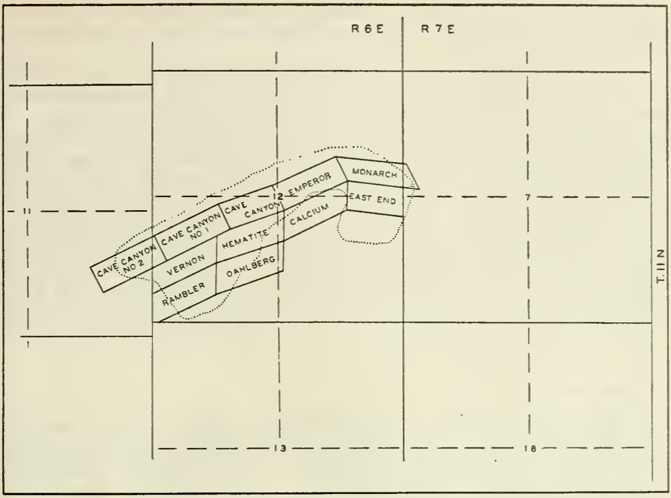
Rock Units

General Relations

The major exposed rock units that are associated with the iron-ore deposits include: (1) a metamorphic group consisting of granitic, gneissic, and somewhat schistose rocks, including some meta-quartzite; (2) acid and basic intrusives, dominantly granite, pegmatite, aplite, and diorite porphyry; (3) crystalline limestone or dolomite; (4) a sandstone-fanglomerate formation; and (5) alluvium. Roughly, with the exception of the intrusives and the alluvium, these units occur in zones trending northeast (Pl. VIII). The limestone forms a conspicuous ridge extending westward for about half a mile along the southern part of the area. The principal mass of iron ore makes a low ridge flanked to the north by gneissic rocks and to the south by the sandstone-fanglomerate.

[1] Cave Canyon iron mine: California Div. Mines, Min. Abstracts, Iron, p. 26, 1941. Hewett, D. F., Callaghan, Eugene, Moore, B. N., Nolan, T. B., Rubey, W. W., and Schaller, W. T., Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, p. 78, 1936.


118°
117°
116°
115°



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As a rule the latter formation occupies lowland areas, but at places it laps high up on the sides of hills, as along the south side of the iron-ore ridge (Pl. VIII).

The age relations of the rocks are not entirely clear. The age of the limestone has been stated to be pre-Cambrian.[2] Field relations indicate that the metamorphic rocks are as old or older than the limestone, as some of them are cut by pegmatite and aplite dikes whereas no dikes of that type were observed cutting the limestone. Possibly the age of the limestone is late pre-Cambrian and that of the gneissic rocks is early pre-Cambrian. Tentatively the age of the diorite porphyry and the iron ore is regarded as later, but there is no proof that the diorite porphyry was intruded later than pre-Cambrian time. It cuts the limestone, and apparently brought about the formation of the iron ore. The sandstone-fanglomerate and the alluvium are classed as Quaternary. The sandstone-fanglomerate rests unconformably on all rocks except the alluvium, the latter being the younger. The structural simplicity of these two units indicates that they formed after the Tertiary.

Description of Units

Metamorphic Group. The metamorphic group includes gneissic and schistose rocks, granitic rocks showing only slightly gneissoid structure, and meta-quartzite showing all gradations from recognizable quartzite into gneiss. These rocks are cut by both acid and basic dikes. Only the more abundant types will be described.[3]

The chief gneissic types are: (1) a gray, gneissoid to porphyritic rock composed chiefly of white feldspar and black to green hornblende and biotite; and (2) a gneissoid granite, mottled in white, pink, light brown, green, and black, containing orthoclase or microcline crystals about 0.2-inch long and 0.1-inch wide. The first of these rocks is chiefly in the northern metamorphic belt, and makes up part of the southern slope of Cave Mountain, whereas the second is chiefly in the zone south of the limestone (Pl. VIII). In addition to these two gneissic rocks, outcrops of red, coarse-grained granite gneiss are present to the north and west, beyond the mapped area. This granite gneiss forms much of Cave Mountain, and large blocks of it rest on the sandstone-fanglomerate and other units.

The meta-quartzite shows all gradations from well-bedded vitreous and argillaceous quartzite into banded granitic gneiss. Most exposures are conspicuously white. Associated with the meta-quartzite is a very siliceous, white to pink rock that becomes slightly brown on weathering. It has a very fine sugary texture, exhibits a well defined lineation at some places, and contains numerous small feldspar crystals. This rock may be a phase of the meta-quartzite or it may be an aplitic granite.

Schistose rocks include biotite, hornblende, and quartz-mica schists. They occur in minor amounts associated with the gneisses and the meta-quartzite.

Acid and Basic Intrusives. The chief acid intrusives are granite, aplite, and pegmatite. The basic intrusives are chiefly diorite porphyry. The granite is white to tan, of medium granitoid texture, and is composed principally of orthoclase and quartz. The aplite and pegmatite,

[2] Hewett, D. F., and others, op. cit., p. 163.
[3] Rock names and descriptions are based on megascopic examination only.

which occur as dikes, are pink to reddish. The latter is composed chiefly of orthoclase or microcline and quartz. The diorite porphyry is dark green but contains conspicuous phenocrysts of white plagioclase. At some places it grades into a diorite lacking phenocrysts and at others into a dark green to nearly black rock composed chiefly of biotite.

Crystalline Limestone or Dolomite. The limestone or dolomite is chiefly white to bluish gray, but some of it is dark gray, light brown, and reddish brown. Much of it is crystalline and could be classed as marble, but there are also fine-grained varieties. Bedded, massive, and brecciated types are present, but exposures exhibiting well-defined bedding are characteristic. Chert is a conspicuous component of some phases of the limestone. It occurs as nodules and lenses, and as beds from a few inches to 4 feet in thickness. Some of the chert has been recrystallized and has a quartzitic appearance. Thin, elongated tremolite crystals, at places associated with brown mica, occur in some outcrops of the limestone.

Sandstone-Fanglomerate. The sandstone-fanglomerate formation is composed of light-gray to brownish-gray, medium- to coarse-grained, moderately indurated sandstone, and gravels ranging from pebble to boulder size. Many of the sand grains are well-rounded and frosted, but others are subrounded to sub-angular and angular. The gravels are rounded to angular. At least some of them have been transported but a very short distance, as they are composed of the same material as the outcrops on which the fanglomerate rests. Part of the sandstone is massive, part of it is well bedded. At some places sandstone alternates with gravel beds, at others the formation is dominantly sand or dominantly gravel. The total thickness of the formation is not known, but one shaft in the mapped area passed through 90 feet of it and did not penetrate any other rock at the bottom. Several hundred feet are exposed in the adjoining area.

Alluvium. The alluvium is of the usual type, composed of various rock fragments.

Structure

Faults, shattered and brecciated zones, and folds, both simple and complex, are the characteristic structural features of the area. Practically all of the main structures trend northeast. The structure of part of the limestone apparently differs from that of the other rocks.

The structure of the limestone composing the ridge along the south side of the area varies from relatively simple to complex. The west-central part of the ridge, which is not shown on the map, is essentially a simple anticline with steeply dipping limbs striking N. 45° E. This anticlinal structure terminates against a fault striking N. 70° W. and dipping 25° N. The beds on the northern side of the fault dip flatly north 18° to 30°, and strike approximately N. 80° E., although the direction of strike varies considerably in short distances. This fault continues along the southern side of the limestone ridge, but there it strikes about N. 45° E. (Pl. VIII), and dips from 25° to 75°. Apparently it is a thrust fault. Northwest of it the beds are relatively flat, but locally they are crumpled into a series of complex folds that lie in a nearly horizontal position.

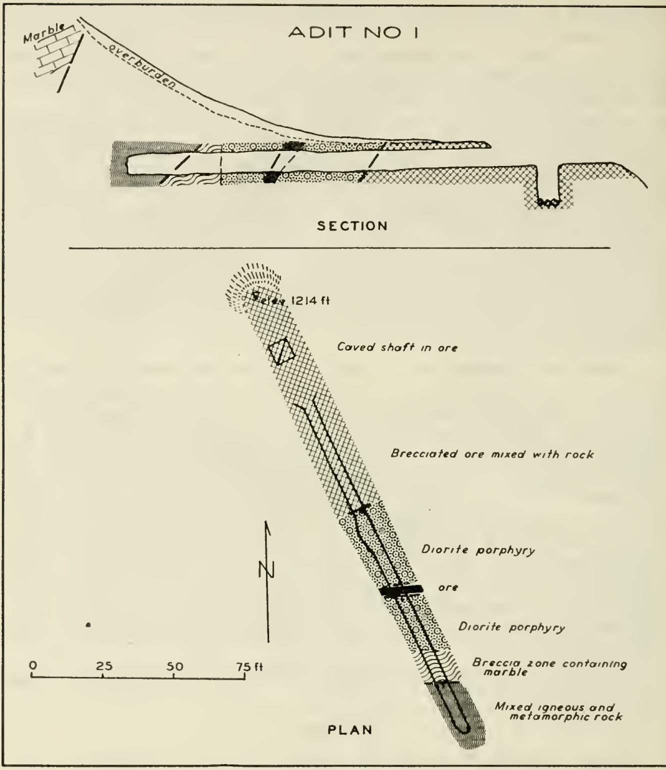

FIG. 25. Plan and section showing geology of No. 1 adit, Cave Canyon iron-ore deposits, Baxter.

Examined in detail, much of the eastern part of the limestone ridge appears to be made up of a series of blocks bounded by faults and brecciated zones. Along the northern side of the ridge there are a number of steeply dipping faults and large quantities of breccia. Much of the breccia appears to have been formed by close folding under relatively light load. The limestone along the northern side of the ridge is separated from the iron ore by faults wherever the contact is exposed. Field evidence is not clear, but apparently these faults are dipping very flatly south, as adits that penetrate some distance beyond the surface exposure of the contact between limestone and iron ore fail to encounter limestone (figs. 25 and 26).

Shearing and shattering are characteristic of some of the gneiss and meta-quartzite, and of much of the iron ore. At some places they are so much shattered that exposures are masses of broken and pulverized rock. Remnants of bedding or foliation indicate steep dips and complex folds.

ORE DEPOSITS

Mineralogy and Occurrence

The ore is black to red, and is composed chiefly of magnetite and hematite, with some limonite. Some brecciated ore masses contain large quantities of gypsum and very minor amounts of malachite and chrysocolla. In surface exposures the ore appears to be relatively firm, but in adits, trenches, and pits most of it is seen to be shattered.

The orebodies are steeply inclined lenticular masses associated with gneissic and quartzitic rock, and limestone. Estimates indicate that the amount of waste rock occurring as scattered masses throughout the ore zone ranges from 25 to 50 percent or more.

Distribution

The deposits consist of two principal ore zones and a few minor orebodies. The most important zone is associated with much shattered gneissic and quartzitic rock in the western part of sec. 12 (Pl. VIII). The other principal zone lies along the northeastern end of the limestone ridge, in the eastern part of sec. 12 (Pl. VIII). A distance of about 2,500 feet separates these two zones. Throughout the intervening area there is alluvium and sandstone-fanglomerate. At one place this intervening area was prospected by a shaft 90 feet deep (Pl. VIII). The only rock encountered in the shaft was the sandstone-fanglomerate.

A few small orebodies occur within the main mass of limestone. One of these is located on the north side of the ridge, near the center of sec. 12 (Pl. VIII). Nearly south of this body, toward the southern side of the limestone, there are a few other small orebodies not shown on the map. The largest of these is about 225 feet long and ranges from 20 feet to 50 feet in width. Ore is exposed throughout a vertical distance of 50 feet. At least half of the orebody consists of waste rock.

Origin

The orebodies are believed to be contact-metamorphic replacement deposits, chiefly in limestone or dolomite but possibly partly in quartzite. The clearest evidence regarding the origin of the ore is shown in the smaller bodies. There are all stages of ore formation, from limestone

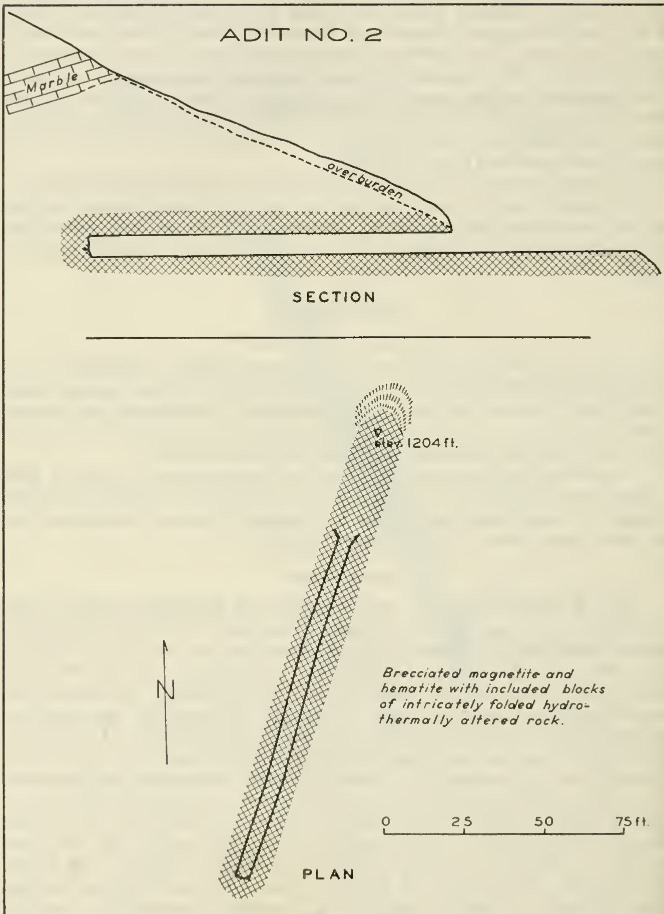

FIG. 26. Plan and section showing geology of No. 2 adit, Cave Canyon iron-ore deposits, Baxter.

containing only minute specks of magnetite through partly replaced limestone into nearly solid ore. At practically every place where ore is exposed, there are also a diorite porphyry and remnants of partially replaced limestone. At one place quartzite occurs next to ore and apparently grades into it. The quartzite has been fractured and the fractures filled with ore. At this place also, the ore may have resulted from replacement of limestone interbedded with quartzite, the limestone having been completely replaced, but there is no direct evidence that this is the case.

ORE RESERVES

The reserves of the area may be as much as 3,500,000 to 4,000,000 long tons of ore, but probably not more than 2,500,000 long tons are recoverable, and not more than half of the recoverable ore could be mined at normal peacetime prices.

The composition of the ore is indicated by the analyses of two samples collected and analyzed by the Kaiser Company, Inc., and one sample collected by the owner, which have been released for publication.

Composition of samples collected and analyzed by the Kaiser Company, Inc., and collected by the owner, Cave Canyon iron-ore deposits, San Bernardino County, California

Sampled by	Percent						
	Fe	*P*	*SiO_2*	*S*	*CaO*	*MgO*	*Al_2O_3*
Kaiser Company	60.00	0.061	5.40	1.01	1.38	0.48	0.31
Kaiser Company	64.60	0.084	2.91	0.043	0.65	0.39	0.58
Owner	67.35	0.122	1.80	----	----	----	----

The reserves are divided into measured, indicated, and inferred ore. The measured ore was estimated from outcrops, pits, trenches, and adits; the indicated ore, from known depth of ore of 220 feet at one place, as shown by surface outcrops and a shaft; and the inferred ore, from inferred depth based on geologic conditions.

The tonnage factor of 12 cubic feet per long ton probably is the best one to use, because of the broken character of the ore; but estimates are given based on tonnage factors of both 10 and 12, after making volume deductions for waste rock (see page 83).

Not all of the reserve ore is believed to be recoverable, due to conditions affecting mining. Estimates of the amount recoverable at normal peacetime prices and at emergency prices are given on page 83.

The estimate of the amount of ore recoverable at normal peacetime prices may be too high, due to the large amounts of shattered waste rock present with the ore.

It is possible that additional ore not considered in these estimates may be present beneath the limestone along the northeast end of the limestone ridge. At the surface, field evidence indicates that the iron ore is in fault contact with the limestone. However, two adits show that iron ore extends beneath the limestone (figs. 25 and 26). Any ore beneath the limestone would need to be recovered by underground methods, and would be minable at emergency prices only, if at all.

FIG. 27. Cave Canyon iron-ore deposit, near Baxter, California. Prospect tunnels and trenches. *Photo by E. F. Burchard, 1926.*

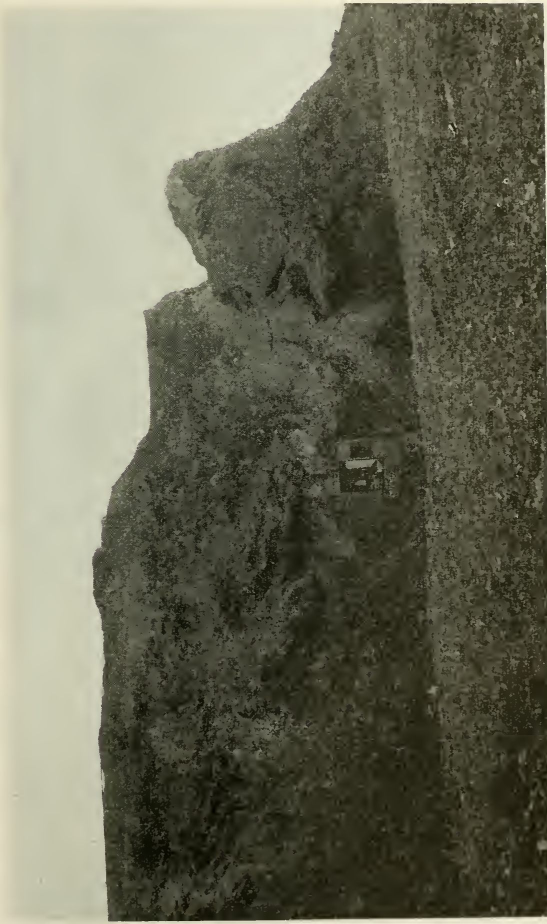

FIG. 28. Cave Canyon iron-ore deposit near Baxter. Shows open cut where iron ore for manufacture of low-heat portland cement is mined by steam shovel. *Photo by E. F. Burchard, 1941.*

FIG. 29. Cave Canyon iron-ore deposit, near Baxter. Open cut near top of ridge. Shows relations of iron ore (black) and light-colored non-ore-bearing associated rock. *Photo by E. F. Burchard, 1941.*

Estimated iron-ore reserves, Cave Canyon iron-ore deposits, sec. 12, T. 11 N., R. 6 E.

Deposit	Ore, long tons, using tonnage factor	
	10 cu. ft. per long ton	12 cu. ft. per long ton
Western deposit, now being mined:		
Measured ore	450,000	370,000
Indicated ore	805,000	675,000
Inferred ore	1,130,000	955,000
Total ore	2,385,000	2,000,000
Eastern deposit:		
Measured ore	175,000	150,000
Indicated ore	560,000	460,000
Inferred ore	985,000	825,000
Total ore	1,720,000	1,435,000
Grand Total, both areas:		
Measured ore	625,000	520,000
Indicated ore	1,365,000	1,135,000
Inferred ore	2,115,000	1,780,000
Total ore	4,105,000	3,435,000

Estimated iron ore recoverable at normal peacetime prices and at emergency prices, Cave Canyon iron-ore deposits, sec. 12, T. 11 N., R. 6 E.

	Ore, long tons, using tonnage factor	
	10 cu. ft. per long ton	12 cu. ft. per long ton
Probable ore recoverable at peacetime prices	1,350,000	1,000,000
Possible additional ore recoverable at emergency prices	1,400,000	1,300,000
Total possible ore recoverable	2,750,000	2,300,000

CONDITIONS AFFECTING MINING

There are two chief factors detrimental to mining these deposits: (1) the large amount of waste rock present with the ore; and (2) the shattered character of the ore and rock. The waste rock is so badly shattered that it will not remain standing as the ore is mined, but must be removed from the pit. The wall rock at the margins of the main orebody is broken and weak. It is probable that open-pit mining could not be carried much beyond the present depth of 35 or 40 feet without serious caving of the walls. If underground mining were attempted, a great amount of timbering would be necessary.

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
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FERRY BUILDING, SAN FRANCISCO

OLAF P. JENKINS
Chief Geologist

SAN FRANCISCO] BULLETIN No. 129—PART F [JUNE 1945

Iron Resources of California

Bulletin No. 129

PART F

Vulcan Iron-Ore Deposit
San Bernardino County, California

By CARL A. LAMEY
Geological Survey, U. S. Department of the Interior

Issued by the
STATE DIVISION OF MINES

VULCAN IRON-ORE DEPOSIT, SAN BERNARDINO COUNTY, CALIFORNIA *

By Carl A. Lamey **
United States Department of the Interior, Geological Survey

OUTLINE OF REPORT

ABSTRACT

The Vulcan iron-ore deposit is in the Mojave Desert, San Bernardino County, California, in secs. 25 and 36, T. 10 N., R. 13 E., S.B , about 9 miles southeast of Kelso, a station on the Union Pacific Railroad.

Limestone of early Paleozoic age and monzonite which appears to intrude the limestone are the chief rocks exposed. Diorite and aplite dikes intrude the monzonite. Fanglomerate and younger alluvium cover the other rocks at places.

The orebodies are contact-metamorphic replacements in the limestone near the contact with the monzonite. The age relations between the limestone and the monzonite are obscure ; at some places the contact is faulted, at others the monzonite appears to be intrusive. The ore is thought to have been brought in by the monzonite.

The ore minerals are chiefly magnetite and hematite, but limonite is present also. The chief gangue minerals are calcite, serpentine, and pyrite.

The reserves in the principal orebody are estimated to be 5,680,000 long tons of ore containing about 50 percent iron. They are subdivided into 1,160,000 long tons of measured ore ; 1,130,000 long tons of indicated ore ; and 3,390,000 long tons of inferred ore. A smaller orebody is estimated to contain at least 315,000 long tons of inferred ore and could well contain several times this amount.

The deposit is owned and mined by Kaiser Company, Inc., Fontana, California. Production started December 1, 1942, with mine installations capable of handling a daily output of 2,500 tons of ore. About 43 percent of the total amount of ore present is expected to be recovered by open-pit mining. The ore is extracted in 50-foot benches, crushed at the mine, and transported by truck over a paved road to Kelso for shipment by rail.

Water is obtained from springs about 1⅝ miles southeast of the deposit, and from the Union Pacific Railroad reservoir about 1 mile south of Kelso.

INTRODUCTION

The Vulcan iron-ore deposit is in the Mojave Desert, San Bernardino County, California, in secs. 25 and 36, T. 10 N., R. 13 E., about 9 miles

* Published by permission of the Director, Geological Survey, U. S. Department of the Interior. Manuscript submitted for publication September 28, 1944.
** Geologist, Geological Survey, U. S. Department of the Interior.

southeast of Kelso, a station on the Union Pacific Railroad (fig. 30). The deposit is reached by a paved road from Kelso.

The orebodies are along the western slope of the Providence Mountains at altitudes ranging from 3,900 to 4,100 feet. West of the Providence Mountains is an alluvium-filled valley, in part of which there are large sand dunes.

The property is owned and operated by the Kaiser Company, Inc., Fontana, California. Production started December 1, 1942; since then about 2,500 tons of ore averaging 52 percent iron has been produced daily.

References to brief articles describing the deposit follow:

Hewett, D. F., Callaghan, Eugene, Moore, B. N., Nolan, T. B., Rubey, W. W., and Schaller, W. T., Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, p. 79, 1936.

Vulcan iron deposit: California Div. Mines, Min. Abstracts, Iron, pp. 30-31, 1941.

Hodge, E. T., Available raw material for a Pacific Coast iron industry: War Dept., North Pacific Division, vol. 3, appendix E-5, California iron ore deposits, pp. 12-13, 1935.

Jones, Charles Colcock, An iron deposit in the California desert region: Eng. and Min. Jour., vol. 87, pp. 785-788, 1909.

Jones, Charles Colcock, The iron ores of California and possibilities of smelting: Am. Inst. Min. Eng. Trans., vol. 53, pp. 306-317; Discussion, pp. 318-323, 1915.

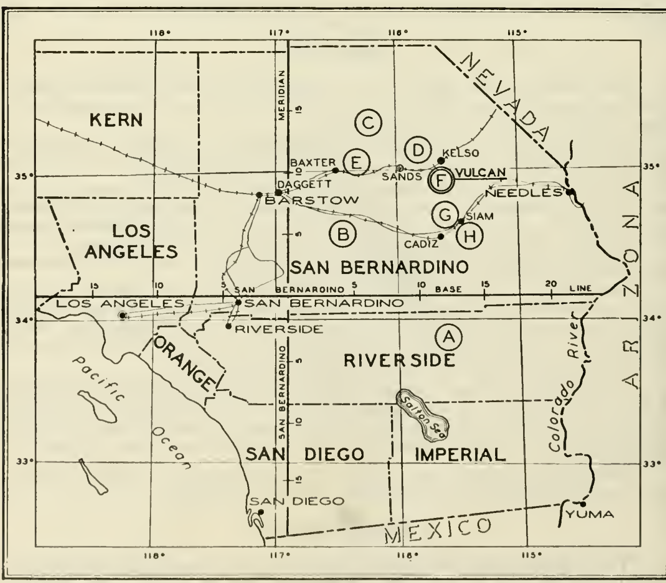


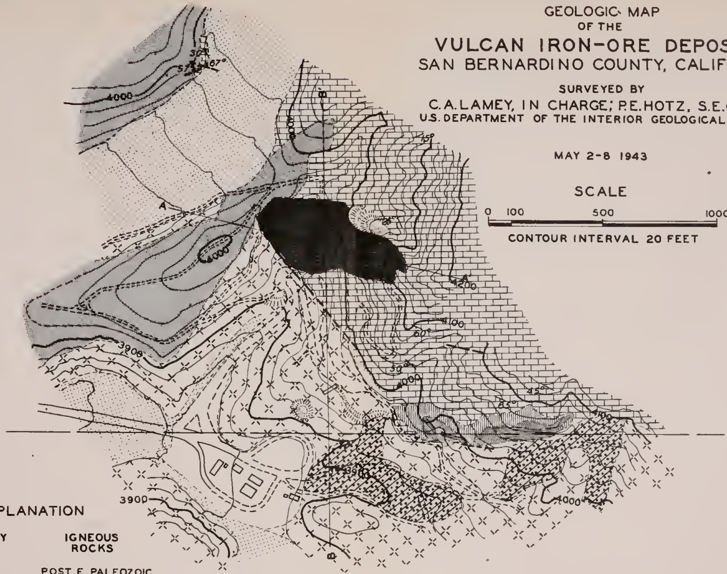
FIG. 30. Index map of southern California iron-ore deposits showing: (A) Eagle Mountains; (B) Iron Mountain (Lava Bed); (C) Iron Mountain (Silver Lake); (D) Old Dad Mountain; (E) Cave Canyon; (F) VULCAN, described in this report; (G) Iron Hat; (H) Ship Mountains.

GEOLOGIC MAP
OF THE
VULCAN IRON-ORE DEPOSITS
SAN BERNARDINO COUNTY, CALIFORNIA

SURVEYED BY
C. A. LAMEY, IN CHARGE; P. E. HOTZ, S. E. GOOD
U.S. DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY

MAY 2-8 1943

SCALE
0 100 500 1000 FEET
CONTOUR INTERVAL 20 FEET



EXPLANATION

SEDIMENTARY ROCKS

QUATERNARY
- ALLUVIUM
- TALUS
- FANGLOMERATE chiefly rhyolite fragments and boulders

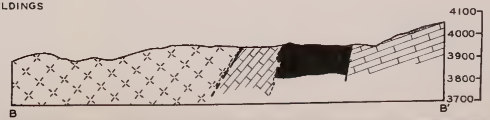
E. PALEOZOIC
- CRYSTALLINE LIMESTONE (moderately well-bedded buff to gray limestone)

IGNEOUS ROCKS

POST E. PALEOZOIC
- MONZONITE including acidic and basic dikes
- IRON ORE
- LEAN IRON ORE

- CONTOURS
- FAULTS
- CONTACTS
- DIP AND STRIKE of bedding
- DUMP
- ROADS solid where paved, dotted where dirt.
- MINE BUILDINGS

Areas possibly containing iron are as indicated by dip needle observations.
- high magnetic attraction
- moderate magnetic attraction



The deposit was examined and mapped during May 1943, by Carl A. Lamey, Preston E. Hotz, and Stanley E. Good. Mapping was done by means of telescopic alidade and plane table. True north was determined by use of the Baldwin solar chart.

ACKNOWLEDGMENTS

Acknowledgment is due to employees of Kaiser Company for courtesies extended in the field, and for the use of material contained in a private report on the geology of the Vulcan iron-ore deposit.

GEOLOGY

General Relations

The rocks [1] exposed include limestone, fanglomerate, alluvium, monzonite, diorite, and aplite (Pl. IX). Rhyolite is exposed about half a mile northeast of the area. The limestone and the monzonite are the most important rocks, as the ore deposits occur in the limestone near its contact with the monzonite. The diorite and the aplite occur only as dikes in the monzonite.

The geologic ages of all rocks are not known, but the relative ages are probably (from youngest to oldest): alluvium, fanglomerate, diorite and aplite dikes, monzonite, limestone. The limestone is early Paleozoic, possibly Cambrian.[2] The age relations between the limestone and the monzonite are obscure. At one place the contact is faulted; at another the monzonite appears to intrude the limestone, and there are minor amounts of pyroxene and amphibole or anthophyllite. The monzonite is probably younger than the limestone. The diorite and aplite dikes intrude the monzonite. The fanglomerate and alluvium are tentatively classed as Quarternary. The relative age of the rhyolite in the area adjoining the deposits was not determined.

Description of Rock Units

Limestone. The limestone is chiefly buff and gray, but it includes white and brown varieties. Much of it is crystalline, but some of it is very fine grained and approaches lithographic limestone. It ranges from massive to thin bedded. The thicker beds are 3 to 6 feet, the thinner ones, half an inch to 2 inches. Chert lenses 3 feet or more long and 2 to 3 inches wide are interbedded with some of the limestone.

Fanglomerate. The fanglomerate is composed chiefly of rhyolite fragments, many of which are several feet long and show flow structure. Other rock fragments are limestone, igneous rock breccia or agglomerate, and metamorphic rocks.

Alluvium. The alluvium is of the usual type, composed of sand and a variety of rock fragments.

Monzonite. The monzonite is coarsely granitoid to slightly porphyritic. Much of it has a mottled appearance, due to pink and lilac orthoclase, white plagioclase, and black biotite. Hornblende, quartz, and light-

[1] Rocks and minerals were identified megascopically only.

[2] Hazzard, John C. Notes on the Cambrian rocks of the eastern Mohave Desert, California (with a paleontological report by Colin H. Crickmay): Univ. California, Dept. Geol. Sci., Bull. 23, pp. 58-60, 75-76, 1933.

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green epidote are present also. The epidote occurs disseminated throughout the monzonite, and as veins as much as half an inch wide. The monzonite is banded at some places, due to segregation of the hornblende and biotite. Serpentinization of parts of the monzonite was noted near faults.

Dikes. The dike rocks are diorite, aplite, and rhyolite. The diorite is dark gray to brownish gray and is finely granitoid. It is partly epidotized, and apparently it caused some epidotization of the monzonite that it cuts. The aplite is conspicuously white, due to the presence of white feldspar. The rhyolite is buff to light brown, and contains visible quartz and orthoclase.

Structure

The structure of the rocks is relatively simple. As a rule the limestone dips to the southwest. Dips range from 15° to 65° and decrease northward. The principal fault trends about N. 45° W., dips about 70° SW., and probably is a normal fault with the downthrown side to the southwest. The other faults trend nearly west.

ORE DEPOSITS

Mineralogy

The ore minerals are chiefly magnetite and hematite, but limonite is present locally. The chief gangue minerals are calcite, serpentine, and pyrite; subordinate amounts of gypsum and copper-bearing minerals are sometimes present. Most of the ore contains only small amounts of gangue, but pyrite is abundant at a few places.

Distribution and Occurrence

The principal exposure of iron ore forms a northwest-trending oval area 700 feet long and 325 feet wide in the SW¼ sec. 25 (Pl. IX). Smaller exposures trending nearly west are present near the quarter corner between secs. 25 and 36.

The principal orebody has a replacement contact with limestone to the east and south, but a fault contact with limestone to the north, and a fault contact with monzonite to the southwest (Pl. IX). The northwest edge of the orebody is covered by fanglomerate, but it appears likely that the faults along the north and the southwest sides of the body intersect and terminate the ore to the norhwest.

The large orebody has been explored by 16 diamond-drill holes and 3 adits. Drill holes range in depth from 116.5 to 897 feet, and all but 4 of them went through iron ore into limestone. One vertical hole passed through 873 feet of iron ore. Two of the adits, about 2,500 feet and 1,400 feet long, passed along the central part of the body and were in ore for most of the distance. The third adit was in monzonite.

The smaller orebody is in contact with limestone except on the south, where it is in fault contact with monzonite. The extent of this orebody is unknown. It has been explored only by a few pits along the south side. Outcrops ranging in width from 5 to 40 feet are present in an area about 650 feet long (Pl. IX). Dip-needle observations show that there is a zone of magnetic attraction 75 to 125 feet wide and 800 feet long surrounding the iron-ore outcrops, although surface exposures in part of the magnetic zone are limestone. The magnetic attraction is highest near

the iron-ore outcrops (Pl. IX); it diminishes abruptly to the south and gradually to the north. It may reasonably be expected, from the distribution and intensity of magnetic attraction, that a body of iron ore about 700 feet long and 50 to 75 feet wide, probably dipping north, occurs in this area.

Chemical Composition

The average composition of the large orebody, based on surface, adit, and drill samples, follows:

Fe	P	Mn	SiO_2	Al_2O_3	CaO	MgO	S	TiO_2	Ign. loss
50.69	0.063	0.11	3.89	1.45	6.30	5.18	1.19	0.20	8.60

The sulphur content varies considerably; the range shown by drill samples is from 0.011 to 3.77 percent. The sulphur content may be higher in the lower part of the orebody than in the upper part, but this relation is not definite or consistent, as is shown by the following table:

Range of sulphur content shown by drill holes, Vulcan iron-ore deposit, sec. 25, T. 10 N., R. 13 E.

Depth from surface	*Number of holes*	*Lowest S content*	*Highest S content*	*Average S content*
0– 50	2	0.201	1.13	0.665
50–100	5	0.050	2.93	1.024
100–150	7	0.011	3.17	0.910
150–200	7	0.027	3.50	0.856
200–250	7	0.764	2.20	1.495
250–300	9	0.152	3.77	1.505

Origin

The orebodies were formed by replacement of limestone. Gradation of limestone into ore showing preservation of bedding and texture of the limestone occurs both at the large orebody and at the smaller one. The contact between the limestone and the monzonite, where it is not faulted, is obscure; but at several places the monzonite appears to intrude the limestone, and at one such contact a light-gray to white pyroxene and a greenish-black, fibrous mineral, possibly amphibole or anthophyllite, were noted, indicating that there had been some contact metamorphism. Serpentine is a characteristic constituent of the Vulcan orebodies, and could well have been formed by hydrothermal metamorphism during intrusion. Serpentine is associated with many of the contact-metamorphic iron-ore deposits of California where the intrusive rock is monzonite or granite. It is thought that the monzonite brought in the Vulcan ore, although the evidence is not clear.

Fig. 31. Part of panorama of Vulcan iron-ore mine near Kelso, California. *Photo by E. F. Burchard, 1943.*

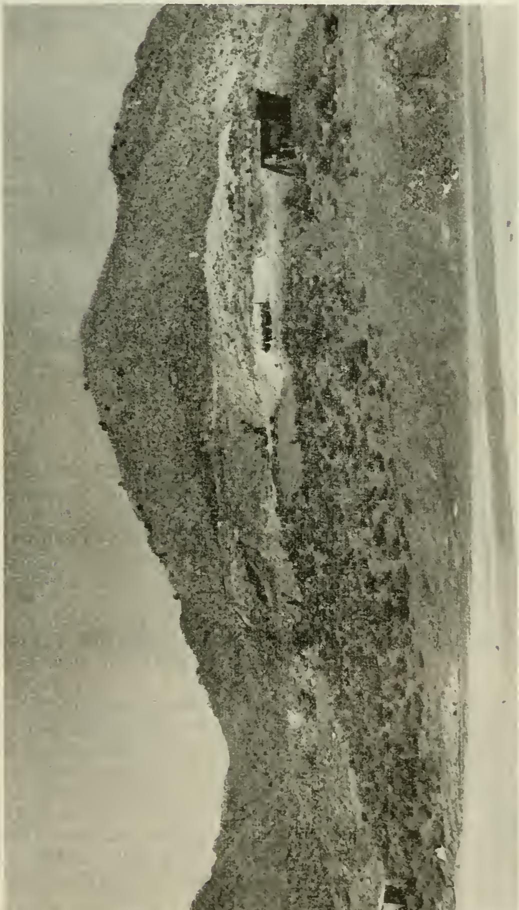

FIG. 32. Part of panorama of Vulcan iron-ore mine near Kelso, California. *Photo by E. F. Burchard, 1943.*

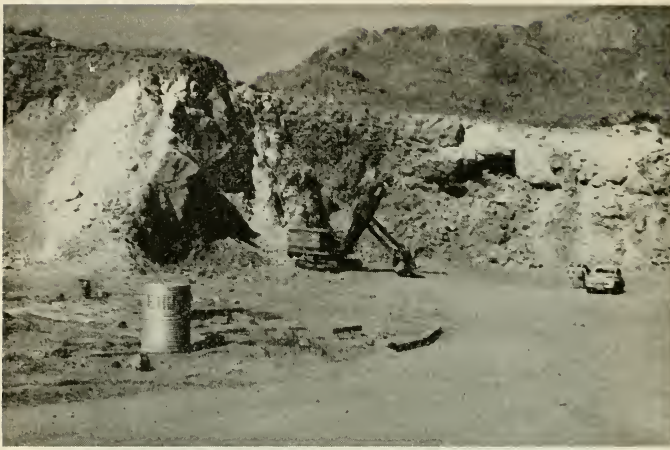

FIG. 33. A bench in open pit of Vulcan iron mine of Kaiser Company, Inc., near Kelso. *Photo by Walter W. Bradley; reprinted from California Journal of Mines and Geology, vol. XXXIX, p. 472.*

RESERVES

The reserves contained in the large orebody are estimated to be 5,680,000 long tons of ore, using a tonnage factor of 10 cubic feet per long ton and deducting 10 percent for waste material. The reserves are subdivided into measured, indicated, and inferred ore, as follows:

Measured ore	1,160,000 long tons
Indicated ore, in addition to measured ore	1,130,000 long tons
Inferred ore, in addition to measured and indicated ore	3,390,000 long tons

The measured ore is contained in three benches, from the top of the pit to the present floor. Exposure is continuous and there is no overburden.

Drill holes and adits indicate that almost continuous ore may reasonably be expected for 100 feet below the present pit floor, the distance to which it is planned to conduct open-pit mining. If so, there should be 1,130,000 long tons of ore in that part of the orebody.

It is inferred that there should be as much as 3,390,000 long tons of ore remaining below the depth to which it is planned to do open-pit mining. This estimate is based on the assumption that ore extends to a depth of 400 feet below the present pit floor, or nearly 600 feet below the uppermost bench. A vertical drill hole near the central part of the orebody shows 873 feet of ore.

In addition to the ore in the large body, it is inferred that there may be at least 315,000 long tons of ore in the smaller body, and there could well be several times this amount. An orebody 700 feet long, 50 feet wide, and 100 feet deep would yield 315,000 long tons of ore. The depth to which ore extends in the large body may well indicate a depth considerably greater than 100 feet in the smaller body.

MINING

The ore is being mined by open-pit methods in 50-foot benches. The limit of open-pit mining will be reached after the extraction of ore from 5 benches. It is estimated that about 43 percent of the total amount of ore will be recovered in this manner. The remaining ore is considered not to be minable except at emergency prices, as it could be extracted only by underground methods.

The capacity of mine installations is 2,500 tons of ore daily. The ore is crushed to 10-inch size by a Traylor 42- by 48-inch Bulldog jaw crusher, and transported by conveyor belts to a storage bin and to trucks. It is shipped from Kelso, where a loading dock has been constructed.

Water is obtained from two springs about $1\frac{1}{4}$ and $1\frac{3}{8}$ miles southeast of the deposit and approximately 500 feet higher than the top of the chief orebody. It is conveyed by gravity through a 1-inch pipe. Water is also obtained from the Cornfield or Union Pacific Spring on the north slope of the Providence Mountains, about 3 miles by airline from the mine. It is piped from the Union Pacific Railroad reservoir 1 mile south of Kelso to a storage tank along the ore haulage road, and thence transported about 4 miles by truck.

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
WALTER W. BRADLEY, State Mineralogist

GEOLOGIC BRANCH
FERRY BUILDING, SAN FRANCISCO

OLAF P. JENKINS
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SAN FRANCISCO] BULLETIN No. 129—PART G [JUNE 1945

Iron Resources of California

Bulletin No. 129

PART G

Iron Hat (Ironclad) Iron-Ore Deposits San Bernardino County, California

By CARL A. LAMEY
Geological Survey, U. S. Department of the Interior

Issued by the
STATE DIVISION OF MINES

IRON HAT (IRONCLAD) IRON-ORE DEPOSITS, SAN BERNARDINO COUNTY, CALIFORNIA *

By Carl A. Lamey **
United States Department of the Interior, Geological Survey

OUTLINE OF REPORT

ABSTRACT

The Iron Hat (Ironclad) iron-ore deposits are in the Mojave Desert, San Bernardino County, California, about 6 miles north of Cadiz, a station on the Atchison, Topeka, and Santa Fe Railroad. They are situated along the south side of the Marble Mountains, at altitudes ranging from 1,450 to 1,850 feet.

It is reported that the Iron Hat deposits are owned by T. Schofield, Amboy, California. The Kaiser Company, Inc., Fontana, California, has investigated parts of the adjacent area to determine the feasibility of operating a limestone quarry and constructing a railroad spur to the quarry. If this should be done, it would facilitate removal of iron ore.

The orebodies are contact-metamorphic replacement deposits, chiefly in steeply dipping Paleozoic limestone near the contact with granite. The structure of the rocks is somewhat complex, due to the presence of a major unconformity, faults, folds, and igneous intrusions of several ages.

The total ore reserves probably do not exceed 285,000 long tons. Adits, trenches, pits, and surface exposures indicate 85,000 long tons of ore of unknown grade. In addition to this amount, a maximum of 200,000 long tons of inferred ore may be present, but geologic conditions indicate that 100,000 long tons is more likely to be correct.

About 2,000 tons of ore reported to contain 65 percent iron was mined and shipped to Los Angeles for experimental purposes some years ago.

INTRODUCTION

The Iron Hat (Ironclad) iron-ore deposits are in the Mojave Desert, San Bernardino County, California, chiefly in sec. 19, T. 6 N., R. 14 E., S.B. (fig. 34). Iron ore is present also in secs. 17, 18, 20, and 21 of

* Published by permission of the Director, Geological Survey, U. S. Department of the Interior. Manuscript submitted for publication September 28, 1944.
** Geologist, Geological Survey, U. S. Department of the Interior.

the same township and range. The deposits are about 6 miles north of Cadiz, a station on the Atchison, Topeka, and Santa Fe Railroad, and are about 3 miles north of U. S. highway 66. They are reached by a dirt road that connects with highway 66 about half a mile west of Chambless store.

Some published reports indicate that the Iron Hat deposits are located in sec. 12, T. 6 N., R. 13 E., and sec. 7, T. 6 N., R. 14 E., and a map of San Bernardino County shows a place known as Iron Hill at that location. A traverse from the quarter-corner between sec. 7 and sec. 13 failed to show the presence of any iron ore. The only rocks exposed in the entire 3 miles traversed are alluvium, granite, volcanic ash and tuff, and andesitic flows. Granite is by far the most abundant of these. At the location known as Iron Hill there is a large hill of weathered granite. The weathered material is rusty brown.

The Iron Hat ore deposits are situated along the south side of the Marble Mountains, at altitudes ranging from 1,450 to 1,850 feet. In the immediate vicinity the mountains attain altitudes of 2,500 to 3,000 feet, and rise abruptly 1,500 to 2,000 feet above an alluvial plain extending southward toward Cadiz. Northward the Marble Mountains attain still higher altitudes.

It is reported that the Iron Hat property is owned by T. Schofield, Amboy, California. The Kaiser Company, Inc., Fontana, California,

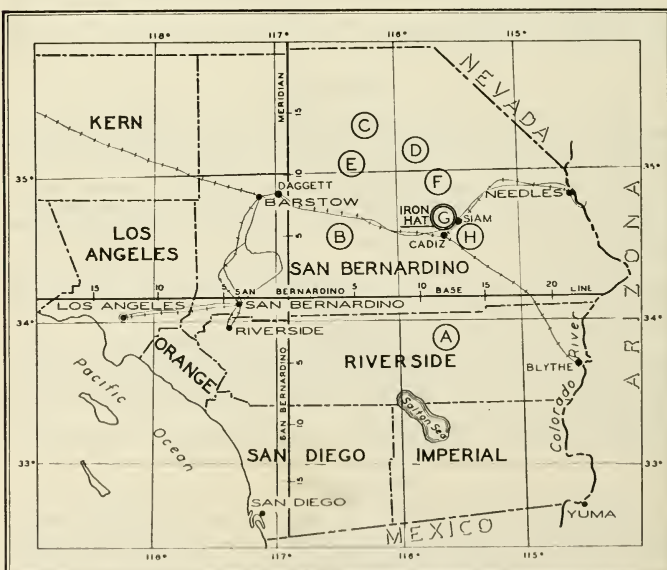


FIG. 34. Index map of southern California iron-ore deposits showing: (A) Eagle Mountains; (B) Iron Mountain (Lava Bed); (C) Iron Mountain (Silver Lake); (D) Old Dad Mountain; (E) Cave Canyon; (F) Vulcan; (G) IRON HAT, described in this report; (H) Ship Mountains.

investigated parts of secs. 17, 20, and 21 to determine the feasibility of operating a limestone quarry and constructing a railroad spur to the quarry. If a railroad spur were constructed, any iron ore that it is feasible to remove could be obtained at relatively low cost.

The orebodies have been explored by a number of pits, trenches, and adits. About 2,000 tons of ore reported to contain 65 percent iron was mined and shipped to the Llewellyn Iron Works at Los Angeles some years ago.

Published material gives very little information regarding these deposits. Brief accounts are contained in the following papers.

Hewett, D. F., Callaghan, Eugene, Moore, B. N., Nolan, T. B., Rubey, W. W., and Schaller, W. T., Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, p. 79, 1936.

Iron Hat group: California Div. Mines, Min. Abstracts, Iron, p. 27, 1941.

The deposits were examined and mapped during April 1943, by Carl A. Lamey, Preston E. Hotz, and Stanley E. Good. Mapping was done by means of plane table and telescopic alidade. Altitude was established from a U. S. Geological Survey bench mark. True north was determined by use of the Baldwin solar chart.

Acknowledgment is due to employees of the Kaiser Company, Inc., for courtesies extended in the field.

GEOLOGY

Rock Units

General Relations

The rock units exposed in the area mapped, and the age tentatively assigned to each one, follow.

Age	*Rock unit*
Quaternary	Alluvium
Post-early Paleozoic	Basic dikes Acid dikes Granite
Early Paleozoic, possibly Cambrian	Limestone and dolomite Quartzite
Pre-Cambrian (?)	Meta-igneous complex

The four major units are the granite, limestone, quartzite, and meta-igneous rocks. In addition to these units, iron ore and contact-metamorphic rocks are associated with granite, limestone, and quartzite.

The distribution of the rock units is somewhat erratic. The major outcrops of granite are in the western part of the area, whereas the major outcrops of quartzite are in the eastern part. Limestone and meta-igneous rocks are present throughout the entire area, the latter rocks occupying the lower slopes along the south side of the Marble Mountains. There are basic and acid dikes throughout the area. Iron ore is present in the western and eastern parts, but contact-metamorphic rocks are chiefly in the eastern part.

The ages tentatively assigned to the various units are based chiefly on the probable age of the limestone. Some fossils noted in it indicate that it is early Paleozoic, possibly Cambrian. The contact between

FIG. 35. The Marble Mountains viewed from highway at Chambless, California. The Iron Hat iron-ore deposit is in one of the lower hills in the front of the range about the middle of the picture. *Photo by E. F. Burchard, 1943.*

the limestone and the underlying quartzite apparently is gradational, but the contact between the quartzite and the meta-igneous rocks is unconformable. Hence it is likely that the meta-igneous rocks are pre-Cambrian. Quartzite and limestone in the same area, near Cadiz, resting unconformably upon pre-Cambrian rocks, have been designated Cambrian.[1] The granite and the dikes cut the meta-igneous and the sedimentary rocks, and must be younger than those units. Flows, ash, and tuff, probably Tertiary, rest on the granite in an adjoining area. Hence it is probable that the age of the granite is post-early Paleozoic and pre-Tertiary.

Description of Rock Units

Meta-Igneous Complex. The meta-igneous complex is composed chiefly of dioritic rock[2] and porphyritic granite, the former being more abundant. The granite apparently intrudes the diorite.

The diorite is gray, but becomes brown on weathering. It is composed chiefly of black to brown biotite and gray to white plagioclase. Quartz is present in minor amounts. The texture is not that of a normal igneous rock, but is somewhat poikiloblastic, i.e., the biotite flakes, which are in common orientation, enclose plagioclase crystals.

The porphyritic granite is pink to slightly green, but becomes brown on weathering. It is composed chiefly of pink to gray orthoclase, white to glassy quartz, and greenish biotite. The orthoclase occurs as prominent phenocrysts as much as 1 inch long and 0.5 inch wide. The crystal arrangement is roughly parallel.

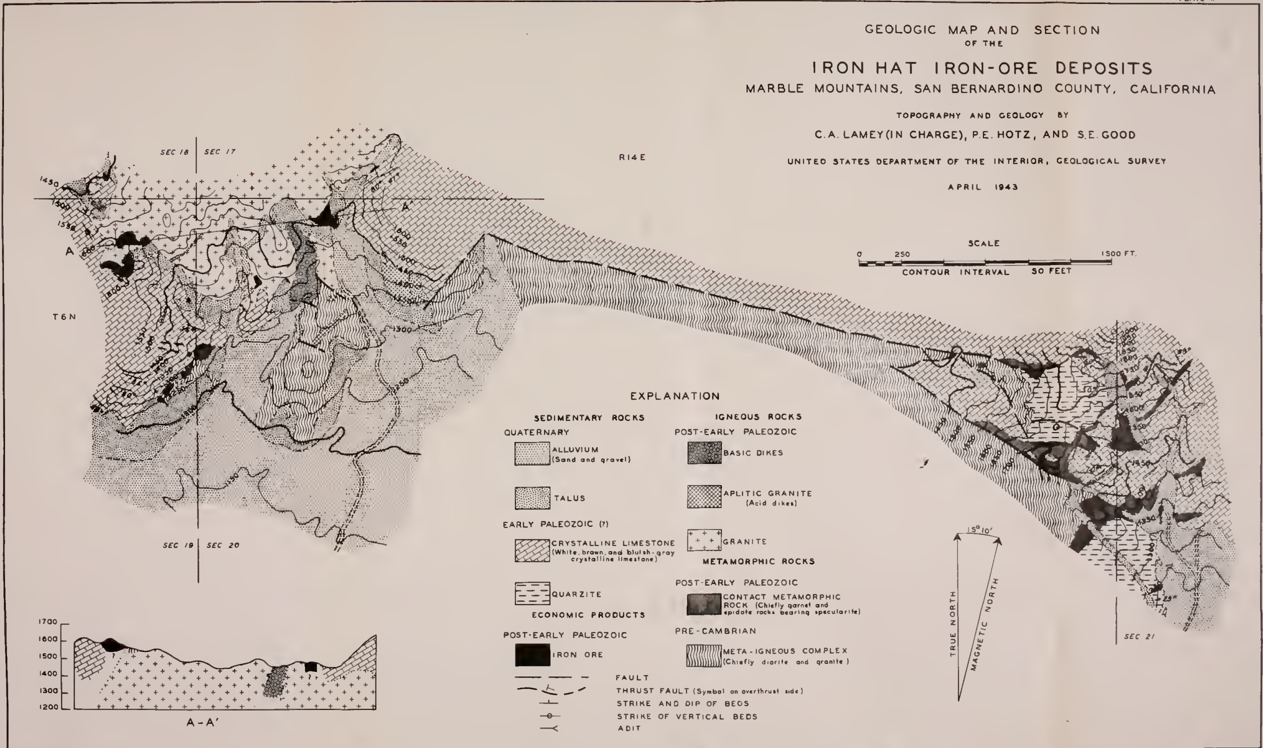
Quartzite. The quartzite is chiefly gray, but some of it is white. It includes both vitreous and argillaceous varieties. Grain size varies from that of silt to that of small pebbles, the predominating size being that of medium to coarse sand. Pebbles are more abundant in the basal part of the formation, and at places conglomerate bands indicate the transition into the underlying meta-igneous rocks. Quartz is the most abundant constituent of the formation, but silty beds contain some biotite, and basal beds contain large amounts of feldspar derived from the meta-igneous rocks. Cross-bedding is a striking and characteristic feature of the quartzite. Gradation in grain size is less conspicuous, but is relatively common. Ripple marks are present at some places.

Limestone and Dolomite. The limestone and dolomite formation varies from buff to gray and nearly white. At some places it is massive, at others it is well bedded. The texture ranges from finely crystalline to coarsely crystalline. The greater part of the formation consists of relatively pure limestone and dolomite, but toward the base it becomes cherty, ferruginous, and argillaceous. The gradational phase from limestone and dolomite into the underlying quartzite consists of at least 100 feet of rock containing chert nodules, lenses, and beds; fine-grained ferruginous limestone; argillaceous limestone; coarsely crystalline limestone; and thin beds of quartzite. Close to the contact between limestone and quartzite some beds contain widely separated well-rounded quartz grains.

[1] Nolan, T. B., The Basin and Range Province in Utah, Nevada, and California. U. S. Geol. Survey Prof. Paper 197-D, p. 148, 1943.

[2] Rock and mineral identifications are based on megascopic examination only.

FIG. 36. Mine workings at the Iron Hat iron-ore deposit near Chambless, California. *Photo by E. F. Burchard, 1926.*


GEOLOGIC MAP AND SECTION
OF THE
IRON HAT IRON-ORE DEPOSITS
MARBLE MOUNTAINS, SAN BERNARDINO COUNTY, CALIFORNIA
TOPOGRAPHY AND GEOLOGY BY
C. A. LAMEY (IN CHARGE), P. E. HOTZ, AND S. E. GOOD
UNITED STATES DEPARTMENT OF THE INTERIOR, GEOLOGICAL SURVEY
APRIL 1943
SCALE
0
250
1500 FT.
CONTOUR INTERVAL 50 FEET
SEC 18
SEC 17
SEC 19
SEC 20
SEC 21
R14E
T6N
A
A'
EXPLANATION
SEDIMENTARY ROCKS
QUATERNARY
ALLUVIUM (Sand and gravel)
TALUS
EARLY PALEOZOIC (?)
CRYSTALLINE LIMESTONE (White, brown, and bluish-gray crystalline limestone)
QUARZITE
ECONOMIC PRODUCTS
POST-EARLY PALEOZOIC
IRON ORE
IGNEOUS ROCKS
POST-EARLY PALEOZOIC
BASIC DIKES
APLITIC GRANITE (Acid dikes)
GRANITE
METAMORPHIC ROCKS
POST-EARLY PALEOZOIC
CONTACT METAMORPHIC ROCK (Chiefly garnet and epidote rocks bearing specularite)
PRE-CAMBRIAN
META-IGNEOUS COMPLEX (Chiefly diorite and granite)
FAULT
THRUST FAULT (Symbol on overthrust side)
STRIKE AND DIP OF BEDS
STRIKE OF VERTICAL BEDS
ADIT
15°10'
TRUE NORTH
MAGNETIC NORTH
1700
1600
1500
1400
1300
1200
A-A'

Granite. The granite includes pink to white varieties, which range from fine grained to coarsely granitoid and porphyritic. It is composed chiefly of pink to white orthoclase and quartz, but it contains a small amount of biotite. Two exceptional differentiates of the granite are (1) a rock composed chiefly of white feldspar and specular hematite, and (2) one composed chiefly of white feldspar and purple fluorite.

Acid Dikes. The chief acid dikes are: (1) white fine-grained aplitic granite; (2) pink pegmatite; and (3) red to brown granite porphyry. The aplitic granite is composed chiefly of white orthoclase and quartz; the pegmatite chiefly of pink orthoclase or microcline, quartz, and biotite; the granite porphyry chiefly of reddish to flesh-colored orthoclase, biotite, and quartz. Quartz apparently is a minor constituent of the granite porphyry at some places, and may be almost absent.

Basic Dikes. The chief basic dikes are: (1) a rock of dioritic to basaltic composition; and (2) hornblende andesite. The dioritic or basaltic dikes are gray to nearly black, and finely porphyritic. Practically the only recognizable mineral is a light-green to light-brown plagioclase that occurs as phenocrysts about 0.1-inch long. The hornblende andesite varies from dark gray to nearly black, but weathers light gray and brown. Characteristically it contains conspicuous hornblende phenocrysts from 0.1- to 0.3-inch long surrounded by a dense groundmass. At some places it contains fragments of other rocks, apparently obtained during the injection of the andesite.

Alluvium. The alluvium is of the ordinary type, composed of fragments of various rocks exposed in the region.

Structure

The structure of the rocks is somewhat complex, due to the presence of a major unconformity, faults, folds, and intrusions of several ages.

The unconformity between the quartzite and the meta-igneous complex is a conspicuous structural feature except where it has been obscured by faulting and folding. It is best exposed about half a mile east of the area mapped, the contact between quartzite and the meta-igneous rocks showing from some distance. Throughout much of the mapped area the meta-igneous rocks are in fault contact with limestone (Pl. X).

Most faults in the area strike northwest, varying from N. 80° W. to N. 45° W., but some of them strike more northerly and others strike northeast. Many of them apparently are normal faults, but at least one low-angle thrust fault was noted, in the NE$\frac{1}{4}$ sec. 20, along which meta-igneous rocks were thrust over limestone.

Folding has caused much variation in strike and dip of the quartzite and limestone. The usual direction of strike is northwest, the dip being steeply northeast or southwest. Locally the strike is almost west or almost north. Some structures pitch approximately south, others pitch southeast.

Many dikes trend northeast and dip northwest. Metamorphic zones developed by intrusions also follow a northeasterly direction. This is well shown in the eastern part of the area (Pl. X).

Granite. The granite includes pink to white varieties, which range from fine grained to coarsely granitoid and porphyritic. It is composed chiefly of pink to white orthoclase and quartz, but it contains a small amount of biotite. Two exceptional differentiates of the granite are (1) a rock composed chiefly of white feldspar and specular hematite, and (2) one composed chiefly of white feldspar and purple fluorite.

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Basic Dikes. The chief basic dikes are: (1) a rock of dioritic to basaltic composition; and (2) hornblende andesite. The dioritic or basaltic dikes are gray to nearly black, and finely porphyritic. Practically the only recognizable mineral is a light-green to light-brown plagioclase that occurs as phenocrysts about 0.1-inch long. The hornblende andesite varies from dark gray to nearly black, but weathers light gray and brown. Characteristically it contains conspicuous hornblende phenocrysts from 0.1- to 0.3-inch long surrounded by a dense groundmass. At some places it contains fragments of other rocks, apparently obtained during the injection of the andesite.

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Many dikes trend northeast and dip northwest. Metamorphic zones developed by intrusions also follow a northeasterly direction. This is well shown in the eastern part of the area (Pl. X).

Fig. 37. Outcrop of magnetite and hematite at Iron Hat iron-ore deposit, near Chambless, California. *Photo by E. F. Burchard, 1926.*

ORE DEPOSITS

Distribution and Extent

The orebodies are all small and apparently very shallow. They are extremely irregular in distribution and are scattered throughout an area 6,000 feet long and 1,000 feet wide. There are three principal deposits and a number of smaller ones (Pl. X). The three principal deposits are located in: (1) the NE$\frac{1}{4}$ sec. 19; (2) the NW$\frac{1}{4}$ sec. 20; and (3) the NE$\frac{1}{4}$ sec. 20. The largest one of these, which is in the NE$\frac{1}{4}$ sec. 19, has a surface area of only 30,000 square feet.

Mineralogy

The ore minerals are chiefly magnetite and hematite, the latter including both massive and specular varieties. In the western deposits magnetite and massive hematite predominate, but much specular hematite is present in the eastern deposits. Magnetite and massive hematite are the prevalent minerals wherever there is much concentration of ore.

The principal gangue minerals are brown garnet, green epidote, green serpentine, and white calcite. Subordinate gangue minerals are a dark-green amphibole similar to actinolite, quartz, and very minor amounts of tremolite and pyrrhotite. Serpentine is the only abundant gangue mineral where there is much ore. It constitutes as much as 5 or 10 percent of some of the western deposits. The other gangue minerals are associated with minor amounts of specular hematite. Greater quantities of specular hematite occur with epidote and amphibole than with garnet. Garnet and epidote are abundant in the eastern part of the area, and are the chief constituents of many outcrops. Commercial production of garnet was attempted on a very small scale at some places.

Occurrence and Origin

The orebodies occur almost exclusively within the limestone, but a very small amount of ore has developed within the quartzite. In the eastern part of the area the more important deposits are near the contact between limestone and quartzite.

The orebodies are contact-metamorphic replacements, chiefly in limestone, and were formed by the intrusion of granite. This is indicated by the constant association of granite and typical contact-metamorphic minerals with the orebodies. At many places specular hematite is present in the granite. Moreover, many bodies of garnet and epidote, containing specular hematite as disseminated crystals and as veins, have the same trend as the granite dikes (Pl. X). Granite is associated with these metamorphic bodies, but is not shown on the geologic map because of the small scale.

ORE RESERVES

The maximum possible ore reserves of all kinds, minable at emergency prices, are estimated not to exceed 285,000 long tons and field evidence indicates that between 150,000 and 185,000 long tons of ore is more likely to be correct. Adits, trenches, pits, and surface exposures indicate 85,000 long tons of ore of unknown grade. Estimates of indi-

cated and inferred ore minable at emergency prices follow. Tonnage was computed after deducting from 10 to 15 percent of the volume for waste rock. A tonnage factor of 10 cubic feet of ore per long ton was used, rather than one of about 8, because the amount of gangue and the number of voids indicated that a factor of 8 probably would be too high.

Reserves of indicated iron ore minable at emergency prices. Iron Hat iron-ore deposits secs. 17, 18, 19, 20, 21, T. 6 N., R. 14 E.

NE¼ sec. 19, depth of ore 75 to 100 feet	52,000 long tons
NW¼ sec. 20, depth of ore 25 to 40 feet	15,000 long tons
NE¼ sec. 20, depth of ore 100 feet	18,000 long tons
Total	85,000 long tons

Reserves of inferred iron ore minable at emergency prices, in addition to indicated ore, Iron Hat iron-ore deposits, secs. 17, 18, 19, 20, 21, T. 6 N., R. 14 E.

NE¼ sec. 19, additional depth of ore 100 feet	132,000 long tons
NW¼ sec. 20, additional depth of ore 100 feet	42,000 long tons
NE¼ sec. 20, additional depth of ore 100 feet	26,000 long tons
Total	200,000 long tons

All field observations indicate that the ore deposits are shallow, and that the additional depth of 100 feet below that used for estimating the indicated ore probably is the maximum depth to which the ore extends. Both in secs. 19 and 20 adits have gone beneath the ore into granite, metamorphic rock, or limestone. The orebody in the NE¼ sec. 20 is probably cut off by a fault within a depth of 100 feet. Ore was encountered at the face of an adit at one place only, in sec. 19.

Minable ore may occur in part of the area in which there are very small surface exposures. However, at most of those places granite crops out very close to ore, and geologic conditions indicate that the orebodies would give place to granite at a short distance beneath the surface.

Two samples collected by the Geological Survey were analyzed by the Kaiser Company, Inc. These analyses follow.

Analyses of samples collected by the Geological Survey, Iron Hat (Ironclad) iron-ore deposits, San Bernardino County, California

Sample number	Location	Composition, percent							
		Fe	P	Mn	SiO_2	Al_2O_3	CaO	MgO	S
1	NW¼, sec. 20, T. 6 N., R. 14 E.	59.20	0.019	0.23	4.85	0.99	0.56	7.70	0.028
2	NE¼, sec. 19, T. 6 N., R. 14 E.	57.60	0.015	0.25	4.18	0.53	2.15	5.22	0.022

In addition to the analyses given above, the results of the analysis of five samples collected and analyzed by the Kaiser Company, Inc., are given below.

Composition of samples collected and analyzed by the Kaiser Company, Inc., Iron Hat (Ironclad) iron-ore deposits, San Bernardino County, California

Description	*Percent*				
	Fe	*P*	SiO_2	*S*	*CaO*
Average of five samples	59.16	0.019	5.04	0.035	1.23

CONDITIONS AFFECTING MINING

The deposit in the NE¼ sec. 19 was mined by open cuts and adits. The ore was trammed down the north side of the mountain to a valley having an altitude about 300 feet lower than the deposit, and then hauled over a dirt road. Buildings of the mining camp are still in fair condition. If a railroad spur were constructed to the proposed limestone quarry, a readily feasible project, the cost of transportation would be materially decreased. An adequate supply of water probably could be obtained if deep wells were drilled near Chambless. Because the amount of ore available is so small, it is unlikely that it could be recovered unless the cost of transportation were low.

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

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GEOLOGIC BRANCH
FERRY BUILDING, SAN FRANCISCO

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SAN FRANCISCO] BULLETIN No. 129—PART H [JUNE 1945

Iron Resources of California
Bulletin No. 129

PART H

Ship Mountains Iron-Ore Deposit San Bernardino County, California

By CARL A. LAMEY
Geological Survey, U. S. Department of the Interior

Issued by the
STATE DIVISION OF MINES

SHIP MOUNTAINS IRON-ORE DEPOSIT, SAN BERNARDINO COUNTY, CALIFORNIA *

By Carl A. Lamey **
United States Department of the Interior, Geological Survey

OUTLINE OF REPORT

ABSTRACT

The Ship Mountains iron-ore deposit is in the Mojave Desert, San Bernardino County, California, in secs. 11 and 12, T. 5 N., R. 15 E., S.B., about 3 miles southeast of Siam, a station on The Atchison, Topeka, and Santa Fe Railroad.

Reserves indicated by an abandoned mine, 4 short adits, and 15 pits and trenches are 42,000 long tons of ore of unknown grade. An additional reserve of 38,000 long tons of ore may reasonably be inferred from known geologic conditions.

The ore is chiefly brecciated hematite. It occurs as lenses in brecciated igneous and metamorphic rocks that strike nearly north and dip about 35° E. Volcanics dipping about 20° E. overlie the ore-bearing rocks, and an irregularly distributed fanglomerate rests on both the ore-bearing rocks and the volcanics at places.

Ore has been traced for three-quarters of a mile along the strike of the ore-bearing rocks, but the ore lenses, which have an average thickness of 2 or 3 feet, are discontinuous, and most of them do not extend more than 250 feet down the dip. The average amount of waste rock is 30 percent, and the overburden is thick. It is unlikely that the ore can be mined except at emergency prices.

INTRODUCTION

The Ship Mountains iron-ore deposit is in the Mojave Desert, San Bernardino County, California (fig. 38), in secs. 11 and 12, T. 5 N., R. 15 E., about 3 miles southeast of Siam, a station on The Atchison, Topeka, and Santa Fe Railroad. A dirt road to the Vulcan gold mine, connecting with U. S. highway 66 about 16 miles east of Amboy, passes within 1 mile of the deposit.

The deposit is situated along the north slope of the Ship Mountains, at altitudes between 1,600 and 1,700 feet. South of the deposit the altitude increases to 2,000 feet in about half a mile, but north of it there is an extensive alluvial plain having an altitude of about 1,300 feet.

Development consists of an abandoned mine, 4 short adits, and 15 pits and trenches (Pls. XI and XII). The mine shaft has an inclination

* Published by permission of the Director, Geological Survey, U. S. Department of the Interior. Manuscript submitted for publication September 28, 1944.
** Geologist, Geological Survey, U. S. Department of the Interior.

of 36° at the collar but flattens to 20° near the bottom. It has a length of 365 feet along the incline and a 61-foot horizontal extension at the bottom, which is 190 feet vertically below the collar. There are 6 levels, 4 stopes, and 830 feet of drifts and crosscuts. Thirty cars of ore reported to average 60 percent iron, low sulphur and silica, and practically no phosphorus, were shipped from the deposit some years ago.

The property is owned by Earl W. Paul, Upland, California.

References to brief articles describing the deposit follow:

Hewett, D. F., Callaghan, Eugene, Moore, B. N., Nolan, T. B., Rubey, W. W., and Schaller, W. T., Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, p. 79, 1936.

Ship Mountains iron mine: California Div. Mines, Min. Abstracts, Iron, p. 30, 1941.

Hodge, E. T., Available raw material for a Pacific Coast iron industry: War Dept., vol. 3, North Pacific Division, appendix E-5, California iron ore deposits, p. 14, 1935.

The deposit was examined and mapped during April, 1943, by Carl A. Lamey, Preston E. Hotz, and Stanley E. Good. Mapping was done by means of telescopic alidade and plane table. True north was determined by use of Baldwin solar chart. Altitude was established from the U. S. Geological Survey bench mark at Siam.

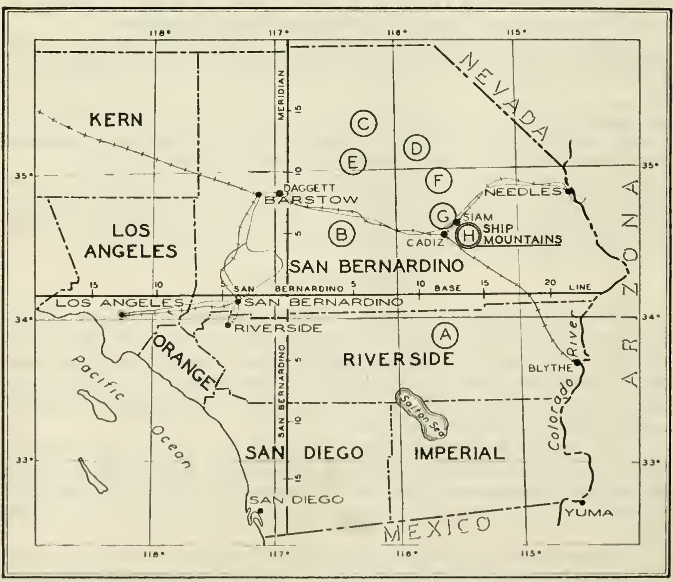
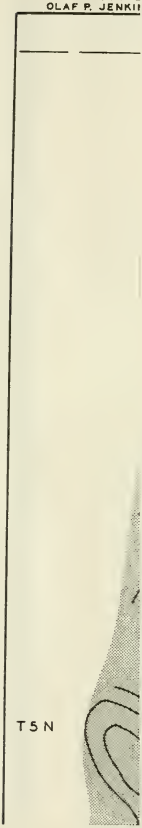
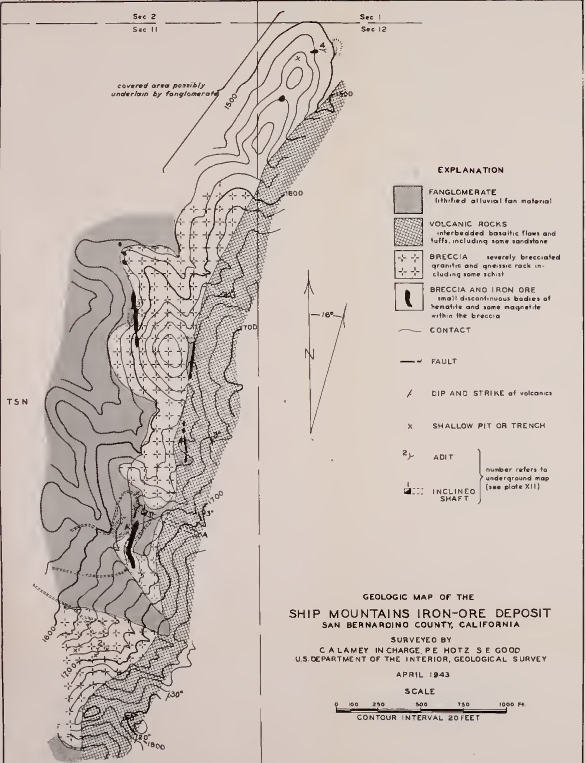
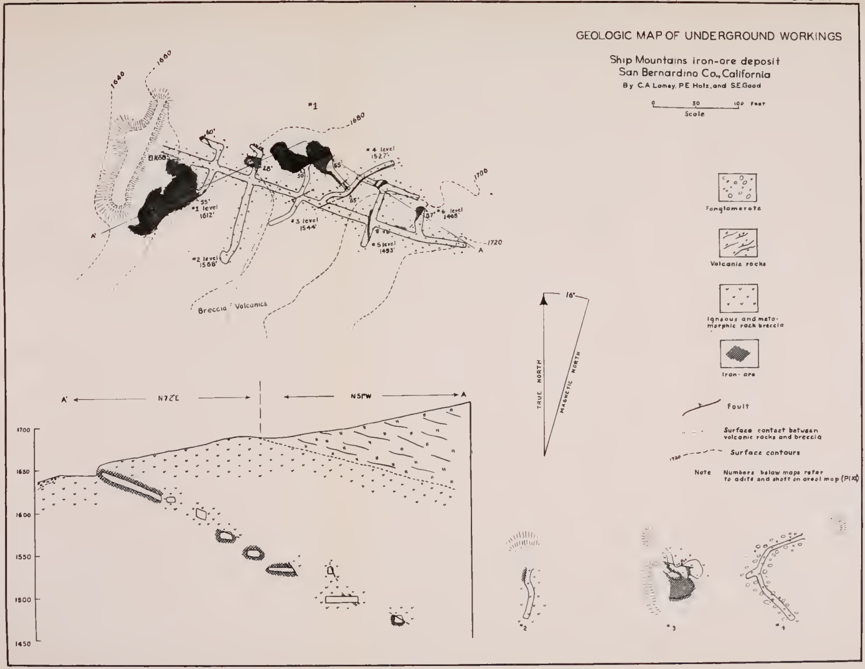


FIG. 38. Index map of southern California iron-ore deposits showing: (A) Eagle Mountains; (B) Iron Mountain (Lava Bed); (C) Iron Mountain (Silver Lake); (D) Old Dad Mountain; (E) Cave Canyon; (F) Vulcan; (G) Iron Hat; (H) SHIP MOUNTAINS, described in this report.

DIVISIO
WALTER W. BRADLE
OLAF P. JENKII




Sec 2
Sec 11
Sec 1
Sec 12
covered area possibly underlain by fanglomerate
1500
1800
1700
T5N
R15E
EXPLANATION
FANGLOMERATE lithified alluvial fan material
VOLCANIC ROCKS interbedded basaltic flows and tuffs, including some sandstone
BRECCIA severely brecciated granitic and gneissic rock including some schist
BRECCIA AND IRON ORE small discontinuous bodies of hematite and some magnetite within the breccia
CONTACT
FAULT
DIP AND STRIKE of volcanics
SHALLOW PIT OR TRENCH
ADIT
INCLINED SHAFT
number refers to underground map (see plate XII)
18°
N
GEOLOGIC MAP OF THE
SHIP MOUNTAINS IRON-ORE DEPOSIT
SAN BERNARDINO COUNTY, CALIFORNIA
SURVEYED BY
C A LAMEY IN CHARGE, P E HOTZ S E GOOD
U.S. DEPARTMENT OF THE INTERIOR, GEOLOGICAL SURVEY
APRIL 1943
SCALE
0 100 250 500 750 1000 Ft.
CONTOUR INTERVAL 20 FEET


GEOLOGIC MAP OF UNDERGROUND WORKINGS
Ship Mountains iron-ore deposit
San Bernardino Co., California
By C.A Lamey, P.E Holz, and S.E Good
0 50 100 Feet
Scale
#1
#1 level 1612'
#2 level 1568'
#3 level 1544'
#4 level 1527'
#5 level 1493'
#6 level 1468'
Breccia : Volcanics
A'
A
N72E
N51W
TRUE NORTH
MAGNETIC NORTH
16°
Fanglomerate
Volcanic rocks
Igneous and metamorphic rock breccia
Iron-ore
Fault
Surface contact between volcanic rocks and breccia
Surface contours
Note Numbers below maps refer to adits and shaft on areal map (Pl XI)
1700
1650
1600
1550
1500
1450
#2
#3
#4

GEOLOGY

General Relations

Brecciated igneous and metamorphic rocks and included lenses of iron ore strike nearly north and dip about 35° E. (Pl. XI). These rocks are overlain by volcanics dipping about 20° E. Fanglomerate having an irregular distribution overlies the other rocks in some places.

The age of the brecciated rocks is unknown, but the volcanics are probably Tertiary.

Description of Rock Units

Brecciated Igneous and Metamorphic Rocks. The brecciated igneous and metamorphic rocks are chiefly white to pink fine-grained granite,[1] pink pegmatitic granite, and fine-grained white and gray granite-gneiss. Dark-green chloritic schist is present in smaller amounts. The iron-ore lenses are associated with the schist.

Volcanic Rocks. The volcanic rocks are chiefly basaltic flows, with which ash, lithic tuff, and sandstone are interbedded. The flows are composed of finely crystalline gray, brown, and reddish basalt, and red to gray scoriaceous and amygdaloidal olivine basalt. The ash and tuff are white to gray. The sandstone is white to gray at the base but reddish toward the top. It is slightly cross-bedded; in some places it contains small pebbles and in others scoriaceous material resembling volcanic bombs.

Fanglomerate. The fanglomerate is composed of light-gray to light-brown sandstone, chiefly coarse and pebbly, interbedded with gravels ranging from small pebbles to boulders 2 feet long. In some places bedding is well developed, but usually it is poorly defined.

Structure

Folds and faults are common in the brecciated rocks. The structure of the volcanics is much less complex, but those rocks also have been displaced by faults. The bedding of the fanglomerate is horizontal as a rule but dips as high as 23° were noted.

ORE DEPOSITS

The ore is chiefly brecciated red to steel-gray hematite but includes some massive magnetite. Waste material constitutes 20 to 50 percent of the ore lenses, and averages about 30 percent. It consists chiefly of granitic and gneissic rock but near faults includes much gypsum and small amounts of copper-bearing minerals.

Ore is exposed in pits and trenches throughout a distance of about three-quarters of a mile along the strike of the ore-bearing rocks. There are two principal exposures in the N½ sec. 11, about 900 feet apart, and a minor one near the northeast corner of sec. 11 (Pl. XI). Each major exposure is about 300 feet long and 20 feet wide.

The average thickness of ore lenses is 2 or 3 feet, but the range is from a few inches to 10 feet or more. Ore was stoped in the mine to a height of about 20 feet. In the stope ore occurred in several lenses separated by waste rock.

The ore lenses are folded, contorted, and faulted, and have little continuity. Ore was mined for 100 feet along the strike in the uppermost level of the mine, but for only 25 feet on the third level. It extends

[1] Rocks were examined megascopically only.

365 feet down the dip in the mine, but the greater volume of ore is within 250 feet of the surface (Pl. XII).

Overburden is only a few feet thick at surface exposures but increases rapidly down the dip of the ore, as the ground surface rises in that direction (Pl. XII).

RESERVES

The reserves indicated by pits, trenches, and adits are 42,000 long tons of ore of unknown grade. An additional reserve of 38,000 long tons of ore may reasonably be inferred from known geological conditions, making the total reserves 80,000 long tons. Because of the broken character of the ore, calculation of reserves was based on a tonnage factor of 12 cubic feet per long ton after deducting 30 percent of the total volume for waste.

Indicated Ore

The indicated ore is contained in the two areas in the N½ sec. 11. Each body has an exposed width of 20 feet, an average dip of 35°, and a probable depth of 100 feet along the dip. The length of one of the bodies is 325 feet, that of the other one is 300 feet.

The composition of the ore is indicated by the analyses of two samples collected and analyzed by the Kaiser Company, Inc., and five samples collected by the owner, which have been released for publication.

Composition of samples collected and analyzed by the Kaiser Company, Inc., and collected by the owner. Ship Mountains iron-ore deposits, San Bernardino County, California

Sampled by	Percent			
	Fe	*P*	*SiO_2*	*S*
Kaiser Company	63.61	0.008	3.06	0.440
Kaiser Company	61.30	0.019	5.22	1.00
Owner (average of five samples)	65.87	0.005	5.16	0.198

Inferred Ore

The inferred ore is based on the assumption that ore extends to a depth of 250 feet down the dip, as indicated by mine workings, and that lenses are continuous throughout only half of the distance of ore exposures. In that case the two deposits in the N½ of sec. 11 contain 31,000 long tons of additional ore, and a small deposit exposed for 70 feet along the strike contains 7,000 long tons of ore, making a total of 38,000 long tons.

CONDITIONS AFFECTING MINING

The large amount of overburden, irregular distribution of ore, and brecciated character of the enclosing rock adversely affect mining. If open-pit mining were attempted, making pits 40 feet deep, it would be necessary to remove 73 cubic yards of overburden for every 100 long tons of ore extracted.

It is unlikely that the deposits can be mined except under emergency conditions, regardless of the fact that the distance to rail transportation is short, and that water is available at Siam and possibly in the alluvial area north of the deposit.

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
WALTER W. BRADLEY, State Mineralogist

GEOLOGIC BRANCH
FERRY BUILDING, SAN FRANCISCO

OLAF P. JENKINS
Chief Geologist

SAN FRANCISCO] BULLETIN No. 129—PART I [JUNE 1945

Iron Resources of California

Bulletin No. 129

PART I

Minarets Magnetite Deposits of Iron Mountain Madera County, California

By PARKER D. TRASK and FRANK S. SIMONS
Geological Survey, U. S. Department of the Interior

Issued by the
STATE DIVISION OF MINES

MINARETS MAGNETITE DEPOSITS OF IRON MOUNTAIN, MADERA COUNTY, CALIFORNIA *

By Parker D. Trask** and Frank S. Simons**
United States Department of the Interior, Geological Survey

OUTLINE OF REPORT

ABSTRACT

The Minarets magnetite deposits are located at an altitude of 10,000 feet near the crest of the Sierra Nevada, 14 miles by trail from the nearest road, and 90 miles from the nearest railroad at Friant, near Fresno, California. Most of the ore is found in an elliptical body 1400 feet in length and 160 feet in maximum width. This body is composed of alternating bands of high- and low-grade ore. The high-grade ore consists of massive magnetite, and the low-grade, of a mixture of magnetite and actinolite. The deposits are undeveloped. Some 2,500,000 tons of rock containing 60 percent iron, 8 percent silica, and 0.35 percent phosphorus are reasonably expectable, and another 2,500,000 tons are inferred.

INTRODUCTION

The Minarets magnetite deposits of Iron Mountain are near the crest of the Sierra Nevada in northeastern Madera County, 100 miles by road and trail northeast of Fresno, California. They crop out in a northwestward-trending zone 15 to 160 feet in width and 1400 feet in length on two sides of a sharp spur extending southwestward from Iron Mountain, at altitudes ranging between 10,000 and 10,550 feet. The deposits are undeveloped. A few small prospect pits and two adits 15 feet in length have been dug, presumably during the last war. The ore consists of two types: (1) high-grade magnetite and (2) a mixture of magnetite and actinolite. Approximately 2,500,000 tons of magnetite ore containing about 60 percent iron, 8 percent silica, and at least 0.35 percent phosphorus, are reasonably expectable, and an additional like amount can be inferred to be present at depth. The inaccessibility of the deposits, the relatively high phosphorus content, and the small tonnage make them less attractive than some of the other western iron deposits that are nearer to the market.

The deposits were mapped on a scale of 100 feet to the inch by plane table with stadia rod and alidade in August 1942 by Parker D. Trask and Frank S. Simons. (Plate XIII.)

* Published by permission of the Director, Geological Survey, United States Department of Interior. Manuscript received for publication September 14, 1944.

** Field geologist of the Geological Survey, United States Department of Interior.

The deposits were first described 50 years ago in early reports of the California State Mining Bureau (Goldstone, L. P. 90, pp. 191-193; Watts, W. L. 93, p. 214). They were visited by Weeks (16) shortly before World War I. More recently they have been described in some detail by Erwin (34). Erwin's report also includes an account of the general geology of the region.

LOCATION

The Iron Mountain, or Minarets, magnetite deposits are located in unsurveyed land, presumably near the boundary between sec. 1, T. 4 S., R. 25 E., and sec. 7, T. 4 S., R. 26 E., M. D. They lie in rugged glaciated country, 1000 feet above timberline. Snow lies on the ground for about eight months in the year, and difficulty would be encountered in mining the deposits during the winter and spring.

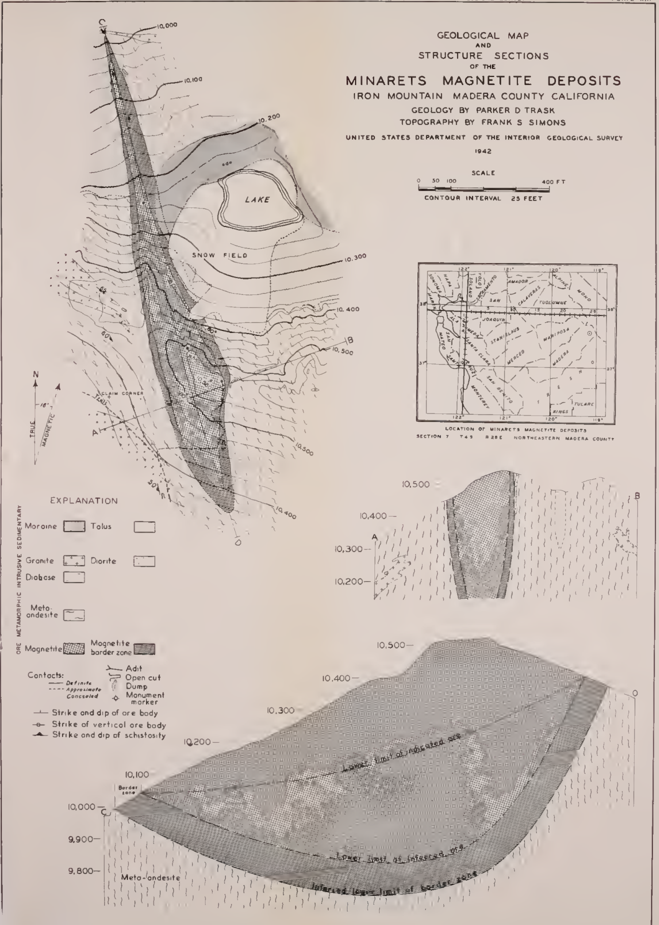
The deposits are 14 miles by trail from the nearest road. They are situated 4 miles north of '77 Corral, which is at the half-way point on the main trail across the Sierra Nevada from Clover Meadow to Devil Postpile. This trail traverses rugged country and climbs and descends more than 1500 feet in each direction from '77 Corral. From Devil Postpile at the east end of the trail a road leads through Mammoth Pass to Mammoth, 13 miles distant. Iron Mountain and the physical features of the surrounding country are shown on the U. S. Geological Survey topographic map of the Mt. Lyell quadrangle. Mammoth is 175 miles by paved highway from the railroad at Mojave, California, and 315 miles from Los Angeles. From Clover Meadow at the west end of the trail, a mountain road extends 35 miles to Bass Lake, mostly by down grade; and from Bass Lake a paved highway goes 40 miles to Friant, the nearest railroad point, and 55 miles to Fresno, in the center of the San Joaquin Valley. A survey for a modern highway is said to have been made along the course of the Mammoth trail, across the Sierra; and if a road is built along this route it would make the deposits more accessible, but in any event the truck haul to a railroad would be long.

OWNERSHIP

The ownership of the claims was not ascertained. One claim corner was found in the southwest part of the mapped area. Three claims were listed in a notice found at the corner: (1) the Bull of the Woods, to the northeast; (2) the Magnetic, to the southeast; and (3) the Second Magnetic, to the southwest. The date indicated on the claim notice is August 20, 1920, and the ownership is listed as N. E. Steel, which presumably refers to the Noble Electric Steel Company. No work has been done on the deposits recently, as all the pits have been partially filled with slumped rock.

Erwin (34, p. 73) states that two patented and eight unpatented claims held in the name of the Noble Electric Steel Company have been taken out. He says:

> "The two patented claims include the massive occurrence of magnetite which outcrops across the ridge directly west of the main peak summit. The other claims include lesser scattered occurrences of magnetite which lie to the southeast in the metamorphic and granite rocks . . . . There are numerous other claims which have been located on the south slope of Iron Mountain, but most of them are believed to be invalid at the present time."


GEOLOGICAL MAP
AND
STRUCTURE SECTIONS
OF THE
MINARETS MAGNETITE DEPOSITS
IRON MOUNTAIN MADERA COUNTY CALIFORNIA
GEOLOGY BY PARKER D TRASK
TOPOGRAPHY BY FRANK S SIMONS
UNITED STATES DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY
1942
SCALE
0 50 100 400 FT
CONTOUR INTERVAL 25 FEET
LAKE
SNOW FIELD
10,000
10,100
10,200
10,300
10,400
10,500
CLAIM CORNER
N
TRUE
MAGNETIC
16°
LOCATION OF MINARETS MAGNETITE DEPOSITS
SECTION 7 T 4 S R 28 E NORTHEASTERN MADERA COUNTY
SONOMA
NAPA
SOLANO
YOLO
SACRAMENTO
AMADOR
CALAVERAS
ALPINE
MONO
TUOLUMNE
SAN JOAQUIN
STANISLAUS
MARIPOSA
MERCED
MADERA
SAN MATEO
SANTA CLARA
SANTA CRUZ
MONTEREY
SAN BENITO
FRESNO
TULARE
KINGS
EXPLANATION
SEDIMENTARY
Moraine
Talus
INTRUSIVE
Granite
Diorite
Diabase
METAMORPHIC
Meta-andesite
ORE
Magnetite
Magnetite border zone
Contacts:
Definite
Approximate
Concealed
Adit
Open cut
Dump
Monument marker
Strike and dip of ore body
Strike of vertical ore body
Strike and dip of schistosity
A
B
C
D
9,800
9,900
Border zone
Meta-andesite
Lower limit of indicated ore
Lower limit of inferred ore
Inferred lower limit of border zone

GEOLOGY

The main orebody is an elongate lens in a sequence of slightly metamorphosed volcanic rocks. The composition of the volcanic rocks varies from dacite to andesite. Some agglomerates and tuffs are present, but in general the rocks seem to be flows. They contain phenocrysts of plagioclase and orthoclase, and are light gray in color. For convenience they are designated as meta-andesite in this report. They strike a little north of west and their dip is vertical.

The meta-andesite is intruded by a series of plutonic rocks. Erwin (34, pp. 33-44) reports masses of different rocks intruded in the following order: andesine diabase, diorite porphyry, diorite, quartz monzonite and diorite, and micropegmatite porphyry. He states that these rock masses vary considerably in composition and in places have indefinite boundaries. The micropegmatite porphyry is the only granitic type that he found in the vicinity of the orebody, but a small dike of a rock that looks like diorite, near the north end of the orebody, may belong to one of the other intrusions (Plate XIII).

Four areas of granite are near the orebody (Plate XIII). Two of these areas of granite are off-shoots from a large mass of granite that is found south and west of the orebody. A third area lies on the main ridge crest northeast of the orebody, and the fourth area seemingly cuts the orebody near the north end. The mass of granite south and west of the orebody clearly is earlier in age than the ore, as it is cut by stringers of magnetite, though at no place is it in contact with the ore. It is a medium-grained rock containing well-formed quartz and orthoclase crystals and minor amounts of plagioclase, hornblende, and epidote. Its areal distribution indicates that it is the micropegmatite granite described by Erwin (34, pp. 42-44). The granite that seemingly cuts the orebody on the north has a much finer-grained groundmass than the main granite body, and may be a different rock.

A few dikes of a fine-grained dark-gray rock, having the texture of diabase, but containing a few orthoclase (?) phenocrysts, are found near the ore. These dikes have a maximum width of three feet. They cut the granite and meta-andesite, but they apparently are younger than the ore as one of them is deflected where it comes in contact with the orebody.

The ore lies parallel to the strike of the meta-andesite. It is completely enclosed within the meta-andesite, and seemingly has replaced it. The orebody thins gradually to the north, but grades into meta-andesite rapidly toward the south. It is 1400 feet long and has a maximum width of 160 feet along section AB.

The ore consists of sheet-like masses of two types: (1) nearly pure magnetite, and (2) mixtures of magnetite and actinolite. The magnetite ore is massive and contains a small amount—less than 10 percent—of actinolite and chlorite. The mixed ore is composed of intimate mixtures of magnetite and actinolite in which actinolite may form as much as 50 percent of the volume of the rock. The actinolite crystals range from an eighth of an inch to 12 inches in length and are arranged in a random pattern. As the actinolite cuts and is cut by magnetite, the ore must have been formed in more than one period. In places, particularly in zones rich in actinolite, the magnetite and actinolite contain fine-grained feldspar suggestive of diabasic texture.

GEOLOGY

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The ore lies parallel to the strike of the meta-andesite. It is completely enclosed within the meta-andesite, and seemingly has replaced it. The orebody thins gradually to the north, but grades into meta-andesite rapidly toward the south. It is 1400 feet long and has a maximum width of 160 feet along section AB.

The ore consists of sheet-like masses of two types: (1) nearly pure magnetite, and (2) mixtures of magnetite and actinolite. The magnetite ore is massive and contains a small amount—less than 10 percent—of actinolite and chlorite. The mixed ore is composed of intimate mixtures of magnetite and actinolite in which actinolite may form as much as 50 percent of the volume of the rock. The actinolite crystals range from an eighth of an inch to 12 inches in length and are arranged in a random pattern. As the actinolite cuts and is cut by magnetite, the ore must have been formed in more than one period. In places, particularly in zones rich in actinolite, the magnetite and actinolite contain fine-grained feldspar suggestive of diabasic texture.

Apparently the ore has been formed in several pulsations, the last pulsation having produced a huge sheet 40 feet in width near the west edge of the orebody. This sheet is resistant to erosion and forms a prominent fin. It strikes at an angle of 5 to 10 degrees with the rest of the orebody; that is, the ore on the east strikes into it at a slight angle and is truncated. This fin breaks down near the crest of the ridge to the south and cannot be traced farther with certainty. The sheet-like masses do not persist for the entire length of the ore. Instead they vary in composition and grade into one or another type of ore along the strike. The ore is cut by veins of actinolite, which range in thickness from a thin film to 3 feet. These veins are clearly later in age than the ore. They dip and strike essentially parallel to the ore. The long axes of the crystals of actinolite are at right angles to the wall of the veins and some of the crystals are a foot in length.

The ore is bordered by a transition zone consisting of recrystallized meta-andesite, actinolite, plagioclase, epidote, and magnetite. The proportion of these rocks and minerals varies and shows no definite relationship with distance from the orebody; good magnetite ore is found in some places at the contact of border zone and the country rock. The main characteristic is the presence of plagioclase crystals up to an inch in length. The boundaries of the border zone, both with the meta-andesite and with the ore, are vague, and a sharp line of demarcation cannot be made; though in general the limits are fairly straight, as shown on Plate XIII. The border zone can hardly be considered as ore, for the magnetite content is low; in no place does magnetite form more than 25 percent of the rock by weight and in most places it forms less than 10 percent. The border zone ranges in thickness between 10 and 50 feet on the east side of the orebody and between 5 and 30 feet on the west side.

The ore zone is covered by a thin veneer of talus to the south, but it appears to play out some 500 feet south of the crest of the ridge. Little magnetite float is found beyond the lower limits of the area in which ore is mapped on Plate XIII; meta-andesite seemingly lies in the projection of the orebody for 200 or 300 yards, beyond which the meta-andesite is cut off by granite. Some 1,000 feet south of the orebody and in the projection of its dip and strike, the granite is cut by a dike of actinolite and plagioclase 30 feet wide.

The dike is very coarse grained, and some of the crystals of actinolite and feldspar are more than an inch in length. In places, small amounts of epidote and magnetite are present. The dike rock is similar to the border zone around the orebody and the dike, therefore, is probably a continuation of the orebody, though at no place is its magnetite content sufficient for it to be regarded as high-grade iron ore.

The dike rock is softer than the surrounding rock and weathers to form a longitudinal depression that can be traced intermittently across the country for 1500 feet to the south. The zone of rocks of the same type as found in the orebody can therefore be traced more or less definitely for about three-quarters of a mile across the country, though the orebody proper is only about a quarter of a mile in length. The straightness of the strike throughout this length suggests that the magnetite came in along a fault or shear zone.

ANALYSES OF ORE

The orebody was sampled in three places: (1) along section AB, shown on Plate XIII; (2) approximately 200 feet north of section AB; and (3) about 75 feet south of the north end of the orebody, approximately at the line of the 10,075-foot contour. All samples were grab samples. The results of the analyses are shown in Tables 1 and 2. Samples of the orebody along section AB were taken from each of the zones of high-grade magnetite, and a single composite sample was collected from all of the zones of mixed ore. Since zones H and J, shown in Table 1, have essentially the same composition and are separated by an actinolite vein only 3 feet thick, a single composite sample was taken from them. The sample on the north side of the ridge 200 feet north of section AB, was collected diagonally across the trend of the orebody because of the roughness of the country. The sample at the north end of the orebody was taken at right angles to the strike. The ore at this place is somewhat richer in actinolite than farther to the south. The border zone of mixed actinolite, feldspar, country rock, and minor amount of magnetite was not sampled.

Table 1—Iron and silica content of Iron Mountain or Minarets iron ore [a]

	Nature of rock Section AB	*Fe (percent)*	*SiO_2 (percent)*	*Thickness (feet)*
A	East border zone consisting mainly of actinolite, feldspar, meta-andesite, and less than 25 percent magnetite			20
B	Massive ore [b]	61.20	6.00	19
C	Mixed ore [c]			21
D	Massive ore	56.85	8.10	13
E	Mixed ore, rich in actinolite			14
F	Massive ore	64.30	6.90	13
G	Mixed ore			7
H	Massive ore, nearly pure magnetite [d]	65.00	4.10	10
I	Actinolite vein			3
J	Massive ore, nearly pure magnetite [d]	65.00	4.10	46
K	Covered—presumably massive ore			14
L	West border zone consisting mainly of actinolite, feldspar, meta-andesite and less than 25 percent magnetite			25
	High-grade zones B, D, F, H, J	63.16	5.33	101
	Mixed-ore zones C, E, G, I (composite sample)	48.68	15.19	45
	Orebody zones B to K, inclusive [e]	59.08	8.10	160
	Mineralized area—zones A to L inclusive			205
	Composite sample of orebody, taken 200 feet north of section AB	60.05	6.88	140
	Composite sample taken at north end orebody at altitude of 10,075 feet—massive ore	50.10	12.45	15

[a] Analysis by Samuel H. Cress, Geological Survey.
[b] The massive ore consists predominantly of magnetite. Actinolite is a minor constituent.
[c] The mixed ore consists of magnetite and a relatively large amount of actinolite.
[d] Composite sample of zones H and J.
[e] Composition of zone K assumed to be same as average of zones B, D, F, H, and J.

Table 2—Complete analyses of typical composite samples of Iron Mountain, or Minarets, iron ore

	High-grade ore composite of Zones H and J [a]	Mixed ore composite of Zones C, E, G, and I [a]	Entire orebody Zones B to K inclusive [b]	Sample reported by Goldstone [c]	Sample reported by Weeks [d]
SiO_2	4.65%	16.22%	7.90%	4.20%	8.60%
Al_2O_3	1.20	4.60	2.16	.54	1.52
Fe_2O_3	63.90	48.30	59.50	----	----
FeO	26.10	19.71	24.30	---- }	
MgO	1.15	4.17	2.00	.02 }	0.53
CaO	2.70	4.02	3.07	2.04 }	
Na_2O	.08	.47	.19	----	----
K_2O	.10	.29	.15	----	----
H_2O-	None	.03	.01	----	----
H_2O+	.35	.58	.41	----	----
TiO_2	.02	.12	.05	----	----
CO_2	Trace	Trace	Trace	----	----
P_2O_5	.79	.85	.81	.57	1.65
S	Trace	Trace	Trace	.04	.60
MnO	.053	.033	.047	.48	----
Li_2O	None	None	None	----	----
Totals	101.09	99.39	100.60	----	----
Fe	65.00	49.12	60.52	66.20	64.14

[a] Analyses by Samuel H. Cress, Geological Survey.
[b] Analyses computed from columns 1 and 2 on assumption that the analysis of composite sample from zones H and J is the same as the analysis of the composite of zones B, D, F, H, J, and K.
[c] Goldstone (90, p. 191).
[d] Weeks (16, p. 558).

Table 1 shows the iron and silica content of the several samples that were taken. Table 2 presents complete analyses of two samples: (1) the composite sample from zones H and J, representing an aggregate thickness of 56 feet, or approximately a third of the total thickness (160 feet) of the orebody, and about half the total thickness of the high-grade ore; and (2) the composite sample from all the mixed zones, representing an aggregate thickness of 45 feet, or about 30 percent of the total thickness of the orebody. Table 2 also contains a column showing the estimated composition of the orebody as computed from the analyses of these two samples on the assumption that the sample from zones H and J represents the true composition of all the zones of high-grade ore. However, as indicated in Table 1, zones H and J are slightly higher in iron and poorer in silica than the other zones of high-grade ore. Consequently allowances for these differences in composition should be made when interpreting the data presented in this column.

As indicated by the analyses shown in Tables 1 and 2 the average composition of the orebody is 60 percent iron and 8 percent silica. The zones of high-grade magnetite contain approximately 65 percent iron and 5 percent silica. The richer magnetite zones lie on the west side of the orebody and one of them, the westernmost, is 50 feet thick for a distance of several hundred feet. It could very easily be mined selectively. The zones of mixed magnetite and actinolite, as indicated by the sample taken along section AB, contain approximately 50 percent

FIG. 39. Looking west toward Minarets iron deposit; U. S. Bureau of Mines drill setup in center. *Photo by C. L. Severy.*

FIG. 40. Looking north from Minarets iron deposit; U. S. Bureau of Mines drill setup in foreground. *Photo by C. L. Severy.*

FIG. 41. Looking north from top of Iron Mountain, the Minarets. *Photo by C. L. Severy.*

FIG. 42. Close-up of U. S. Bureau of Mines diamond-drill setup, Minarets iron deposit. *Photo by C. L. Severy.*

FIG. 43. U. S. Bureau of Mines diamond-drill setup, Minarets iron deposit. *Photo by C. L. Severy.*

iron and 15 percent silica. However, as they form less than a third of the orebody, they could be mined with the high-grade magnetite without bringing the iron content much below 60 percent and the silica content above 10 percent—at least in the central part of the lineal extent of the orebody. Toward the north the average content of iron in the orebody tends to decrease, for near the north end of the orebody, where its width is only 15 feet, the average content of iron is 50 percent and of silica 12.5 percent.

The main disadvantage of the ore is the high phosphorus content. Each of the composite samples of high- and low-grade ore represented in columns 1 and 2 of Table 2 contain about 0.8 percent P_2O_5 or 0.35 percent phosphorus. Five samples mentioned by Goldstone (90, p. 191) range between 0.13 and 0.75 percent phosphorus, and have an average of 0.41 percent phosphorous, which is close to the average of $0.35 percent for the composite samples collected by the writers. This quantity is considerably higher than that desired by American steelmakers. The phosphorus in part is in the form of apatite. Manganese, titanium, lithium, and sulphur content is low, though the sample mentioned by Weeks contains 0.6 percent sulphur. The other samples however contain less than 0.04 percent sulphur.

RESERVES

The orebody is exposed for about 1400 feet along the strike, and for 500 feet down the dip on the north and 200 feet on the south. The average width is 100 feet in the southern 900 feet of its extent, and 25 feet in the northern 500 feet. Its limits therefore are fairly well outlined, and a line can be drawn between the two ends of its linear extent, as shown on Plate XIII, which gives a lower boundary for what can be considered indicated ore. The volume of rock within these limits is 20,000,000 cubic feet, or 2,500,000 tons, of ore. This ore as indicated by the analyses contains about 60 percent iron, 8 percent silica, 0.35 percent phosphorus, and a trace of sulphur. Approximately two-thirds of the ore, or 1,500,000 tons, is estimated to consist of high-grade magnetite containing about 64 percent magnetite and 5 percent silica.

If the ore extends to a depth of half its linear extent, the bottom of the ore would be approximately as indicated by the lower line in Plate XIII, and another 2,500,000 tons would be present. Reserves of all classes are estimated to be 5,000,000 tons. Surrounding this ore is a border zone consisting principally of actinolite, feldspar, and country rock, and minor amounts, most certainly less than 25 percent of magnetite. The inferred reserves of this border zone are 2,000,000 tons, but the rock contains so little iron that it cannot properly be considered ore.

The best part of the orebody is perched on the two sides of a ridge, which would make mining easy, except during the snow season. However, 14 miles of difficult mountain road would have to be built before the ore could be transported to the nearest rail-head 90 miles away. These difficulties coupled with the relatively high phosphorus content of the ore do not make the deposits particularly attractive at the present time.

BIBLIOGRAPHY

Boalich, E. S.

21 Madera County: California Min. Bur. Rept. 17, p. 84, 1921.

23 Notes on iron ore occurrences in California: California Min. Bur. Rept. 18, p. 111, 1923.

Bradley, Walter W.

27a The Minarets district, Madera County: California Min. Bur. Rept. 22, pp. 456, 557, 1927.

California State Mining Bureau

06 The structural and industrial materials of California: California Min. Bur. Bull. 38, p. 298, 1906.

Dougherty, Ellsworth Y.

27 Magnetite deposits of Madera County, California, constitute important reserves: Eng. and Min. Jour., vol. 123, pp. 765-770, 6 figs., 1927.

Erwin, Homer D.

34 Geology and mineral resources of northeastern Madera County, California: California Div. Mines Rept. 30, pp. 61-65, 1934.

Goldstone, L. P.

90 Fresno County: California Min. Bur. Rept. 10, pp. 191-193, 1890.

Harder, Edmund Cecil

12 Iron-ore deposits of the Eagle Mountains, California: U. S. Geol. Survey Bull. 503, p. 8, 1912.

Hodge, Edwin T.

35 Report on available raw materials for a Pacific Coast iron industry; 5 vols., 1935. War Dept., Corps Eng., U. S. Army, Office of Div. Eng., North Pacific Div., Portland, Oregon. *Minaret deposits*: vol. 1, p. 41; vol. 3, ap. E-5, p. 12.

Laizure, C. McK.

28a Madera County: California Div. Mines Rept. 24, pp. 337-343, 1928.

Lyon, David A.

14 The electric furnace in pig-iron manufacture: U. S. Bur. Mines Bull. 67, p. 40, 1914.

Watts, W. L.

93 Fresno County: California Min. Bur. Rept. 11, p. 214, 1893.

Weeks, F. B.

16 The Minaret iron deposit: California Min. Bur. Rept. 14, pp. 555-558, 1916.

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Iron Resources of California

Bulletin No. 129

PART J

Hirz Mountain Iron-Ore Deposits Shasta County, California

By CARL A. LAMEY
Geological Survey, U. S. Department of the Interior

Issued by the
STATE DIVISION OF MINES

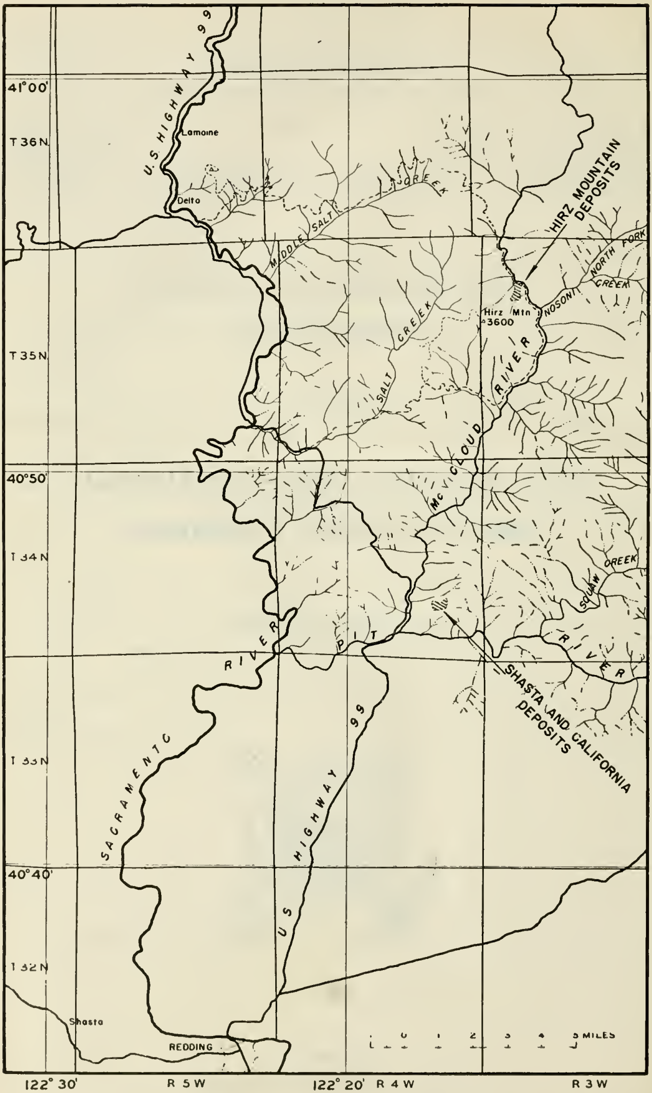

FIG. 44. Index map showing location of the Hirz Mountain and the Shasta and California iron-ore deposits, Shasta County. *Prepared from Forest Service topographic map of Shasta National Forest (west half), California, Mt. Diablo meridian, 1936.*

HIRZ MOUNTAIN IRON-ORE DEPOSITS, SHASTA COUNTY, CALIFORNIA *

By Carl A. Lamey **

United States Department of the Interior, Geological Survey

OUTLINE OF REPORT

ABSTRACT

The Hirz Mountain iron-ore deposits are about 24 miles approximately N. 20° E. of Redding, California. They are near the McCloud River and lie along the brushy lower slopes that form the northeastern approach to Hirz Mountain, at altitudes ranging from 1300 to 1700 feet. They are difficultly accessible over a rough mountain road.

Much of the bedrock of the area is covered. The rocks exposed are (1) the Permian (?) McCloud limestone, (2) the Permian Nosoni formation composed of pebbly and tuffaceous sediments interbedded with basaltic and andesitic flows, and (3) a late Jurassic or early Cretaceous quartz diorite. The distribution of outcrops indicates that the Nosoni formation and the McCloud limestone probably occupy much of an area previously mapped as underlain by quartz diorite, and that locally along the strike the Nosoni formation is separated from the McCloud limestone by a fault.

Relatively few and poor exposures, and generally weak magnetic attraction, indicate that two small zones of iron ore are present, separated from each other by about 1200 feet of quartz diorite and limestone. The iron ore is chiefly magnetite, which occurs as partial replacements of the McCloud limestone and the Nosoni formation, and as disseminations and small stringers in both of these formations and in the quartz diorite. Locally the ore is accompanied by garnet and epidote, and near some deposits the limestone has been partly silicified. Apparently the quartz diorite rose along the contact between the McCloud limestone and the Nosoni formation and produced the few small iron-ore deposits.

The orebodies are probably very discontinuous and shallow. Exposures and magnetic attraction indicate that the reserves probably do not exceed a few hundred thousand tons.

INTRODUCTION

The Hirz Mountain iron-ore deposits are in secs. 5, 7, and 8, T. 35 N., R. 3 W., M.D., Shasta County, California, about 24 miles in a north-

* Published by permission of the Director, Geological Survey, United States Department of the Interior. Manuscript submitted for publication February 24, 1945.

** Field geologist of the Geological Survey, United States Department of the Interior.

easterly direction from Redding (see fig. 44). They are at altitudes ranging from 1300 to 1700 feet and lie along the lower slopes that form the northeastern approach to Hirz Mountain, the crest of which attains an altitude of 3600 feet. The slopes along which the deposits lie are exceedingly brushy and are rather steep and irregular, being cut by a number of intermittent streams (see Pl. XIV).

The deposits are difficultly accessible. In the late summer of 1944 they could be reached by driving north from Redding about 18 miles over U. S. Highway 99, and thence from the vicinity of Salt Creek about 13 miles over the McCloud River road (see fig. 44). The McCloud River road is narrow, rough, and poorly graded. Earlier in the summer, part of it was covered by water ponded by the Shasta dam on the Sacramento River. Complete filling of the Shasta reservoir will cause flooding to an altitude of 1070 feet, and it is understood that the deposits cannot again be reached from the McCloud River road. The only other means of access is by driving considerably farther over a Forest Service mountain road that leaves U. S. Highway 99 near Delta, or by barge on the McCloud River from the vicinity of the Shasta and California deposits (see fig. 44) if such service can be obtained.

Between August 29 and September 20, 1944, a plane-table topographic and geologic map and a dip-needle survey were made of the most promising parts of the deposits and enough of the surrounding area to show the general geologic relations. In this work the writer was ably assisted by P. Dean Proctor. Inasmuch as the extent of the iron-ore deposits did not appear to be sufficient to warrant mining, even on a small scale, and as other work that required the writer's attention was already in progress, the project was discontinued before completing what might otherwise have been considered a desirable geologic unit. This lack of completeness of the mapping, and the very poor exposures in much of the area, make the position of formation boundaries very uncertain.

PREVIOUS PUBLICATIONS

Practically nothing has been published about the Hirz Mountain deposits. The general geology of the region in which they are located was discussed by J. S. Diller, and the deposits mentioned briefly [1].

GENERAL GEOLOGY

Rock Succession, Distribution, and General Relations

The succession of rocks exposed in the area mapped follows:

Succession of rocks exposed near the Hirz Mountain iron-ore deposits

Igneous rocks
- Late Jurassic or early Cretaceous
  - Quartz diorite

Sedimentary and metamorphic rocks
- Quaternary
  - Alluvium and colluvium
- Permian
  - Nosoni formation and metamorphic rocks derived from it
- Permian (?)
  - McCloud limestone and metamorphic rocks derived from it

[1] Diller, J. S., U. S. Geol. Survey Geol. Atlas, Redding folio (no. 138), 14 pp. 1906. Logan, C. A., Shasta County, iron, Jennings group: California Min. Bur. Rept. 22, p. 190, 1926.

Colluvium [2] mantles the greater part of the lower slopes leading up to Hirz Mountain, and alluvium fills much of the bottom of the McCloud River valley and the lower parts of its tributary valleys. Little of the colluvium, except some small patches that appear to be remnants of high terrace deposits, is shown on the map in order that the probable distribution of the underlying formations can be depicted. Inasmuch as the areas of actual rock exposures are shown separately, the distribution of the colluvium is readily inferred.

One small exposure of alluvium was mapped separately because it differs materially from the rest. Apparently it is older than the main mass of alluvium, but the age relations are obscure.

Exposures of Nosoni formation are found chiefly in the McCloud River and along its banks, but a few higher exposures indicate that this formation is present along the lower slopes in a considerable part of the area (see Pl. XIV).

The McCloud limestone rises high above the east side of the McCloud River in a prominent exposure, and a few small outcrops project above the alluvium in the valley of a tributary stream, but the chief exposures of this formation are on the higher slopes to the westward, where they continue beyond the area mapped.

The principal exposures of quartz diorite are along the intermediate slopes, between the Nosoni formation and the McCloud limestone, but dikes of diorite cut both of these formations (see Pl. XIV), and such dikes are much more numerous in unmapped exposures of McCloud limestone farther west.

A comparison of the present map with the one in the Redding folio reveals one important difference. The folio map does not show Nosoni formation west of the McCloud River but indicates quartz diorite in the area shown by the present map to be occupied in part by Nosoni formation and in part by McCloud limestone cut by quartz diorite. Some of the outcrops along the McCloud River clearly are sedimentary rocks, and others are flows interbedded with the sediments. One of the few small exposures in the covered area shows bedding, and the others appear to be very fine-grained flows. Hence the tentative boundary of the Nosoni formation was placed considerably west of the McCloud River. To the north of the Nosoni formation there are a few outcrops of McCloud limestone and of diorite. Since the limestone is practically unmetamorphosed and conforms approximately in strike and dip to the large limestone mass east of the river, it seems more likely that the rocks are chiefly McCloud limestone cut by quartz diorite intrusions rather than chiefly quartz diorite that surrounds a few limestone remnants.

Description of Formations

Alluvium and Colluvium. Most of the mappable alluvium consists of the usual collection of sand and coarser fragments that would be expected along stream courses. One very small patch mapped separately contains fragments that are considerably more weathered than those in the other alluvium, and that are moderately well cemented. The colluvium consists chiefly of fragments of the rocks exposed in the immediate

[2] *Ed. Note.* Colluvium: heterogeneous aggregates of rock detritus, such as talus and avalanches, resulting from the transporting action of gravity. A general term applicable to several grades or types. Definition from *Dictionary of Geological Terms* by C. M. Rice, p. 82, 1940.

vicinity, but locally it is composed of more or less rounded fragments of iron ore, and well-rounded fragments of jasper and some dark-colored igneous rocks. Some of the jasper fragments are several feet in diameter.

Nosoni Formation. The exposures of Nosoni formation consist chiefly of sediments interbedded with lava flows. The sedimentary parts of the formation range from nearly olive-drab or greenish-brown, thinly bedded muddy and silty material, to a gray and greenish rock composed of fine sand and small pebbles embedded in a fine-grained matrix that appears to be tuffaceous. In some of the flows, small but sharply defined plagioclase, and perhaps also olivine, are discernible under a lens. Most of the flows are traversed by small streaks of epidote or show some degree of epidotization. The flows appear to be basalts or andesites.

Near the quartz diorite, trenches expose small amounts of dark-gray to greenish rock, some of which contains epidote, garnet, and magnetite, the latter as small disseminated crystals and as veinlets. Much of this rock has been sheared, so that there is difficulty in determining whether it belongs to the Nosoni formation or to the quartz diorite. However, as it generally is finer grained than the definite exposures of contact quartz diorite, and as some of it is slightly pseudo-porphyritic, the likelihood is that it is somewhat metamorphosed rock of the Nosoni formation.

McCloud Limestone. In general the McCloud limestone is light gray to nearly white, and finely crystalline. Some of it contains a considerable amount of chert, which is present as lenses and nodules. Near the larger masses of diorite the limestone is more coarsely crystalline and some of it is essentially a marble. Locally garnet, epidote, and a pyroxene, probably hedenbergite, are present, or the limestone is partly silicified.

Several small cavern openings were noted in the McCloud limestone just west of the exposures mapped. It is of some interest to note that a short distance south of the Hirz Mountain area, deposits in caverns in the McCloud limestone were found to inclose numerous bones of Pleistocene animals.[3]

Quartz Diorite. Most of the exposed quartz diorite is gray and relatively coarse grained. Some of it is light colored and has a spotted appearance produced by the contrast between nearly white plagioclase and dark hornblende or augite. Some of it contains a considerable amount of pyrite, the decomposition of which facilitates its weathering to brownish rubble and sand.

Structure

Scarcity of exposures and the small area mapped make the interpretation of structure uncertain. In general the dip of the sedimentary rocks is between 30° and 60° to the northeast, but one limestone exposure in sec. 6 shows a dip to the southeast (see Pl. XIV). A number of small faults and shear zones trend either northwest or northeast, and dip steeply. In general the dikes follow the same structural trends as the faults.

Apparently a fault of some magnitude separates the Nosoni formation from the McCloud limestone in sec. 5. The large exposure of lime-

[3] Diller, J. S., op. cit., p. 3.

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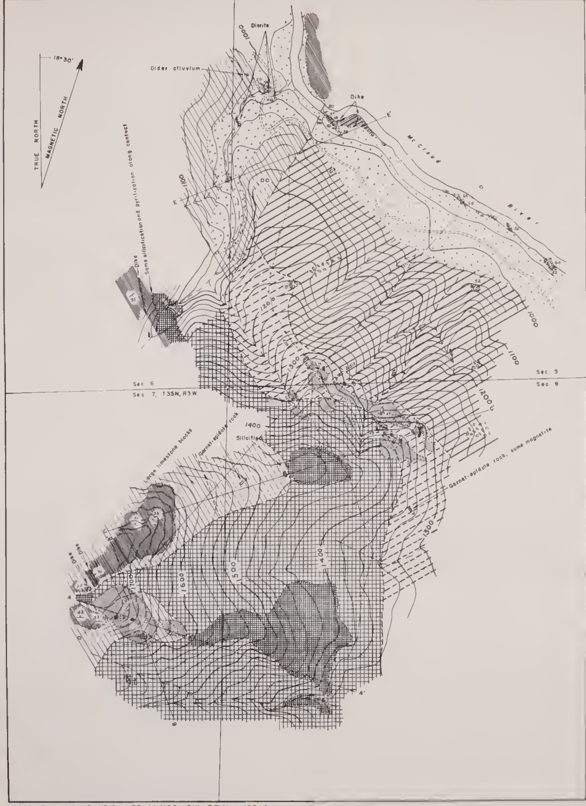

EXPLANATION

IGNEOUS ROCKS

LATE JURASSIC OR EARLY CRETACEOUS

Partly exposed quartz diorite

Covered area probably underlain by quartz diorite

Quartz diorite dike

SEDIMENTARY AND METAMORPHIC ROCKS

QUATERNARY

Alluvium

Older alluvium (cemented)

Colluvium. Float composed of rounded fragments of iron ore and other material; probably high terrace deposits

PERMIAN

Exposed Nosoni formation. Pebbly and tuffaceous sediments interbedded with andesitic and basaltic flows

Covered area probably underlain by Nosoni formation

Partly metamorphosed Nosoni formation, chiefly covered. Contains some garnet and epidote, and some iron ore

PERMIAN(?)

Exposed McCloud limestone, contains some chert

Covered area probably underlain by McCloud limestone

Partly metamorphosed McCloud limestone, chiefly covered. Contains some garnet and epidote, and some iron ore, some of it is silicified

ECONOMIC FEATURES

Exposed iron ore (magnetite and some hematite)

Covered area probably underlain by small bodies of iron ore near the surface, as indicated by magnetic attraction and a few trenches

Covered area probably underlain by rocks containing small magnetite veins and some disseminated magnetite, as indicated by magnetic attraction

MISCELLANEOUS SYMBOLS

Probable fault, position and direction doubtful

Known fault or shear, and inclination

Vertical shear

Strike and dip of bedding

Formation boundary, position doubtful

Trench

Forest Service telephone line

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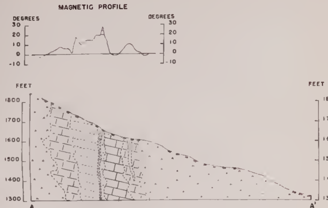
GEOLOGIC AND TOPOGRAPHIC MAP OF THE HIRZ MOUNTAIN IRON-ORE DEPOSITS, SHASTA COUNTY, CALIFORNIA

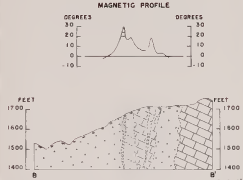
Scale
0 200 400 600 800 Feet

Contour interval 20 feet

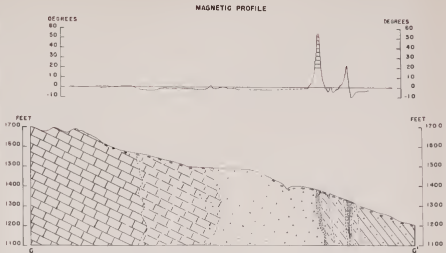
C. A. Lamey and P. D. Proctor, August - September, 1944



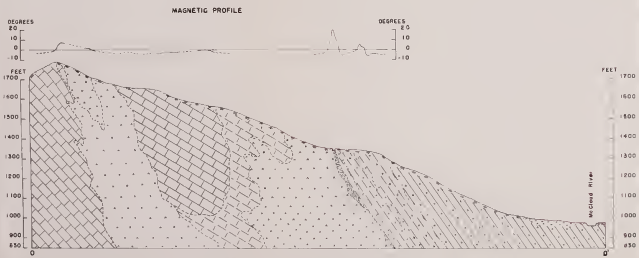
GEOLOGIC SECTION AND MAGNETIC PROFILE ALONG LINE A-A'



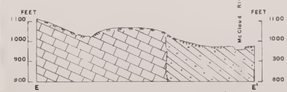
GEOLOGIC SECTION AND MAGNETIC PROFILE ALONG LINE B-B'



GEOLOGIC SECTION AND MAGNETIC PROFILE ALONG LINE C-C'



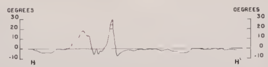
GEOLOGIC SECTION AND MAGNETIC PROFILE ALONG LINE D-D'



GEOLOGIC SECTION ALONG LINE E-E'

MAGNETIC PROFILE ALONG TRAVERSE LINE F-F'

MAGNETIC PROFILE ALONG TRAVERSE LINE G-G'



MAGNETIC PROFILE ALONG TRAVERSE LINE H-H'

MAGNETIC PROFILE ALONG TRAVERSE LINE J-J'

MAGNETIC PROFILE ALONG TRAVERSE LINE K-K'

MAGNETIC PROFILE ALONG TRAVERSE LINE H-L

EXPLANATION

IGNEOUS ROCKS

Quartz diorite (Late Jurassic or early Cretaceous)

SEDIMENTARY AND METAMORPHIC ROCKS

Alluvium

Colluvium

Nosoni formation (Permian) Pebbly and tuffaceous sediments interbedded with andesitic and basaltic flows

Partly metamorphosed Nosoni formation Contains some garnet and epidote

McCloud limestone (Permian?) Contains some chert

Partly metamorphosed McCloud limestone Contains some garnet and epidote; some of it is partly silicified

ECONOMIC FEATURES

Iron ore (magnetite and some hematite)

Iron ore and metamorphosed McCloud limestone, probably carbonate-silicate rock

Partly metamorphosed McCloud limestone probably containing small amounts of iron ore

McCloud limestone probably containing small magnetite veins and perhaps some disseminated magnetite

Iron ore and partly metamorphosed Nosoni formation.

Quartz diorite probably containing small magnetite veins and some disseminated magnetite

MISCELLANEOUS SYMBOLS

Probable fault, position and inclination doubtful

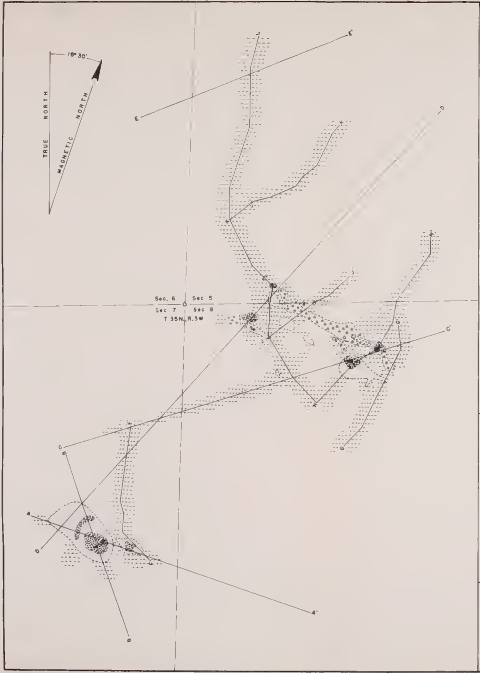
Part of magnetic profile that probably indicates iron ore relatively near the surface, magnetic values higher than 20°

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GEOLOGIC SECTIONS AND MAGNETIC PROFILES, HIRZ MOUNTAIN IRON-ORE DEPOSITS, SHASTA COUNTY, CALIFORNIA

Scale
0 200 400 600 800 feet

Field work by C. A. Lamey and P. D. Proctor, August-September, 1944



EXPLANATION

DIP NEEDLE VALUES

POSITIVE VALUES		NEGATIVE VALUES	
	Above 20°		-10° to -15°
	10° to 20°		-5° to -10°
	0° to 10°		0° to -5°

MAGNETIC PROFILE AND GEOLOGIC SECTION

A — A'

MAGNETIC PROFILE ONLY

K — K'

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

MAGNETIC MAP
HIRZ MOUNTAIN IRON-ORE DEPOSITS
SHASTA COUNTY, CALIFORNIA

Scale
0 200 400 600 800 Feet

Field work by C. A. Lemay and P. D. Proctor, September, 1944

stone on the east side of the river rises several hundred feet above the neighboring outcrops of the Nosoni formation, which strike in the same general direction as the limestone.[4] Because the critical area is covered, a fault was not actually observed. Several small faults and dikes cut the Nosoni formation nearby.

ECONOMIC GEOLOGY

Ore Deposits

Exposures and magnetic attraction indicate that only two small zones of ore deposits are present, one in the NE¼ sec. 7, the other chiefly in the NW¼ sec. 8, at altitudes of approximately 1700 and 1300 feet respectively. They are separated from each other by about 1200 feet of quartz diorite and limestone (see Pl. XIV and section D-D′, pl. XV). These zones lie partly within and partly adjacent to the quartz diorite, near its contacts with the McCloud limestone and the Nosoni formation.

Fragments of iron ore scattered over the area may create an erroneous impression of the extent of the deposits. The relatively steep slopes cause migration of iron-ore fragments to considerable distances. Also, some of the fragments are associated with remnants of high terrace deposits. Magnetic traverses indicate that iron ore is present in only a small part of the area over which the fragments are distributed.

The ore consists chiefly of magnetite, but some hematite is present also. All of the exposed ore is considerably weathered. Much of it contains numerous cavities and openings partially filled with limonitic and clay-like products of decomposition. Very little pyrite was noted in the ore, but it is probable that at least part of the limonitic material was derived from pyrite. No character samples were collected because they probably would give erroneous value owing to the weathered character of the ore.

The few and poor exposures of ore and the spotted and generally weak magnetic attraction (see Pls. XV and XVI), indicate that the ore zones are characterized by local partial replacements of the McCloud limestone and the Nosoni formation, and by disseminated magnetite and small magnetite stringers in both of these formations and in the quartz diorite. Apparently the quartz diorite rose along the contact between the McCloud limestone and the Nosoni formation and produced the few small deposits that are present. Most exposures indicate that the mineralization was feeble. At the best exposure of the contact between the quartz diorite and the limestone, in the SE¼ sec. 6 (see Pl. XIV), the contact is marked merely by some silicification and pyritization.

Reserves

Exposures indicate that the orebodies are exceedingly discontinuous and are likely to be shallow, and that the reserves are very small indeed. An adit about 100 feet long near the boundary between secs. 5 and 8 cuts completely through the lower ore zone. Although a few pieces of ore were noted on the dump, and there is weak magnetic attraction at the

[4] Because of the lack of time and the difficulty of crossing the McCloud River, the topography and geology on the east side of the McCloud River were not mapped. The limestone forms a bold cliff, and the bedding is clearly seen from the west side of the river to be striking and dipping approximately the same as that in the exposures of Nosoni formation in and along the banks of the river, but the dip of the limestone steepens somewhat abruptly toward the northeast side of the exposure.

surface, no ore is exposed in the adit. A second small adit driven beyond a fault that cuts across a trench east of an intermittent stream in the northern part of sec. 8 exposes only fine-grained quartz diorite that contains some veinlets or iron ore along fractures.

The very spotty character of the magnetic attraction, and the lack of persistence of high magnetic values throughout an area of any appreciable size, also indicate that many of the bodies are shallow and that only a few small lenses of good ore are present. The geologic sections, magnetic profiles, and magnetic map (Pls. XV and XVI), show that there are only 3 very small areas yielding dip-needle values higher than 20°, and that there are but 7 areas yielding values higher than 10°, and 3 areas yielding values lower than –10°. Drilling at the Shasta and California deposits (see fig. 44), where geologic conditions are nearly the same as at Hirz Mountain, has shown that there is little likelihood of much ore being present near the surface unless dip-needle values exceed 20° or are less than –20° over an area of considerable size.

If it be assumed that the areas yielding dip-needle values of 10° or higher or of –10° or lower are underlain by ore, which is a very generous assumption, the reserves of inferred ore are as follows, using a tonnage factor of 10:

Upper zones	170,000 tons per 100 feet of depth
Lower zone	90,000 tons per 100 feet of depth
Total	260,000 tons per 100 feet of depth

It seems doubtful that many of the small iron-bearing bodies extend beyond a depth of a few hundred feet, and it is likely that a number of them do not attain a depth of 100 feet. Therefore, the reserves probably do not exceed a few hundred thousand tons, and apparently the ore could not be mined and transported profitably.

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
W. BURLING TUCKER, State Mineralogist

GEOLOGIC BRANCH
FERRY BUILDING, SAN FRANCISCO

OLAF P. JENKINS
Chief Geologist

SAN FRANCISCO] BULLETIN NO. 129 PART K [OCTOBER 1946

Iron Resources of California

Bulletin No. 129

PART K

Shasta and California Iron-Ore Deposits Shasta County, California

By CARL A. LAMEY
Geological Survey, U. S. Department of the Interior

Issued by the
STATE DIVISION OF MINES

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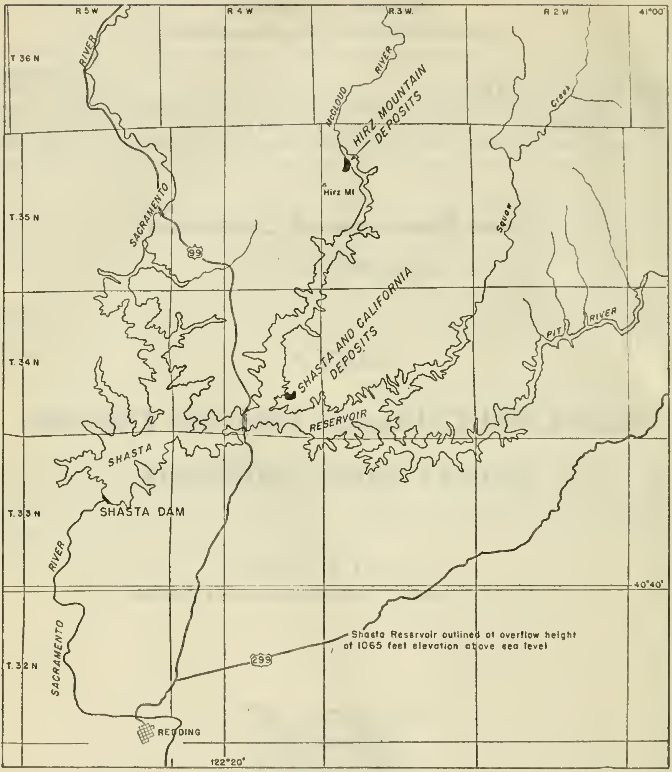


FIG. 45. Index map showing locations of Hirz Mountain, and Shasta and California iron-ore deposits, Shasta County, California.

SHASTA AND CALIFORNIA IRON-ORE DEPOSITS, SHASTA COUNTY, CALIFORNIA *

By Carl A. Lamey **

OUTLINE OF REPORT

ABSTRACT

The Shasta and California iron-ore deposits are in the southern part of the Klamath Mountains at altitudes ranging from 1,300 to 1,700 feet, about 12 miles north of Redding, Shasta County, California. They are close to U. S. Highway 99, but as they lie between the Pit and McCloud Rivers, the valleys of which have been flooded by the building of the Shasta dam on the Sacramento River, the deposits can be reached only by barge or boat.

The deposits consist of very discontinuous and irregular lenses of magnetite intercalated between lenses composed chiefly of garnet, epidote, and pyroxene, accompanied by some serpentine, a mineral resembling anthophyllite, and small amounts of pyrite and chalcopyrite. In general the deposits lie between a late Jurassic or early Cretaceous quartz diorite and the Permian (?) McCloud limestone, and were formed by contact-metamorphic replacement and by fracture filling. In addition to iron, materials introduced by the mineralizing solutions include silica, some manganese and chromium, probably alumina, and perhaps magnesia.

* Published by permission of the Director, Geological Survey, U. S. Department of the Interior. Manuscript prepared 1945; submitted for publication May 7, 1946.

** Geologist, Geological Survey, U. S. Department of the Interior.

The structure of the rocks is somewhat obscure, but two dominant structural trends are apparent, one of which is nearly northeast, the other nearly northwest. A magnetic map compiled from detailed dip-needle observations shows that the ore zone follows these two directions, especially the one trending northeast.

The total reserves, estimated by the Geological Survey from the magnetic map, mine pits, and five diamond drill holes put down by the Bureau of Mines, U. S. Department of the Interior (Project No. 934), amount to 4,680,000 tons of ore having the following percentage composition: Fe, 37.82; SiO_2, 13.24; S, 0.173; P, 0.014; Mn, 0.273. If all material containing less than 25 percent iron is omitted from consideration, the reserves estimated by the Geological Survey amount to 3,893,000 tons containing 41.28 percent iron. About 40 percent of the ore analyzed contains more than 40 percent iron, about 21 percent of it more than 50 percent iron, and only 4 percent of it more than 60 percent iron.

Production began about 1892 and has been continued intermittently under the urge of war conditions or for experimental treatment of the ore. Ore for Navy ballast was being mined in 1944 from open pits by Carrico and Gautier, general contractors, 365 Ocean Avenue, San Francisco, California, and transported to the crusher at Redding by trucks that were ferried across the lake to U. S. Highway 99 on barges operated at irregular intervals by the U. S. Reclamation Service. The present period of production began about February 1, 1942, and has been at the rate of approximately 100,000 tons a year.

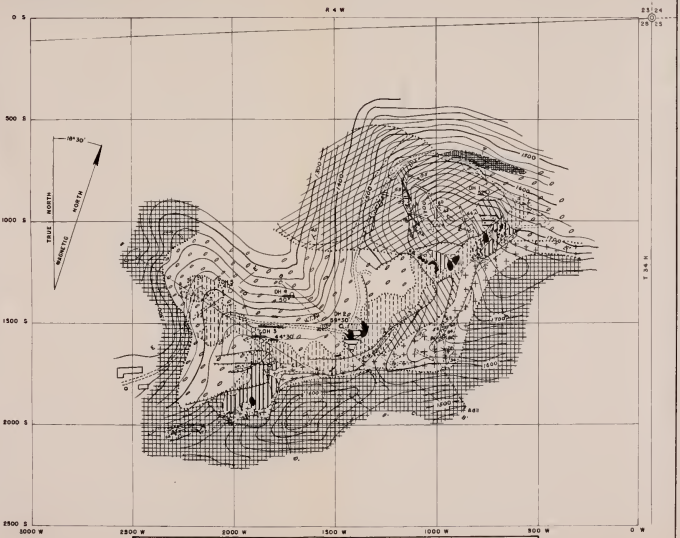
INTRODUCTION

The Shasta and California iron-ore deposits are in Shasta County, California, about 12 miles north of Redding (see fig. 45). They are in the extreme southern part of the Klamath Mountains, a short distance north of the head of the Sacramento Valley, and are in sec. 26, T. 34 N., R. 4 W., between the Pit and the McCloud Rivers, at altitudes ranging from 1,300 to 1,700 feet. The deposits are adjacent to U. S. Highway 99, near the Pit River bridge, but are isolated from the roads of the area by water ponded by the Shasta dam on the Sacramento River. They can be reached by private boat, or by a barge operated at irregular intervals by the U. S. Reclamation Service, and then by driving about 2 miles over a crooked and poorly graded dirt road.

Some ore was mined as early as 1892. Since then production has been continued intermittently under the urge of war conditions or experimental treatment of the ore. Between 1907 and 1926 the ore was mined for the Noble Electric Steel Company, which had a plant in sec. 26, adjacent to the deposit. Ore for Navy ballast was being mined in 1944 from open pits by Carrico and Gautier, general contractors, 365 Ocean Avenue, San Francisco, California, and transported to the crusher at Redding by trucks ferried across the lake on Reclamation Service barges. The present production began about February 1, 1942, and through 1944 was maintained at the rate of approximately 100,000 tons a year.

The deposits were explored during the summer of 1944 by the Bureau of Mines which put down five diamond-drill holes—2,890 feet of drilling. This exploration was chiefly on the property of the Shasta Iron Company whose office is at 384 Second Street, San Francisco, California, but also on the property of the California Consolidated Mines, which is represented by Mr. R. J. Anderson, 1427 California Street, Redding, California.

A geologic map was made with a plane table by the author, who utilized a topographic base made by the Bureau of Mines; a magnetic map was made from dip-needle data. The mapping was not started until after the exploration was nearly completed. The magnetic work, however, was done in considerable detail, and slightly more than 1,500 dip-



UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BUREAU OF MINES PROJECT 534

GEOLOGIC AND TOPOGRAPHIC MAP OF A PART OF THE SHASTA AND CALIFORNIA IRON-ORE DEPOSITS, SHASTA COUNTY, CALIFORNIA

Scale
0 200 400 600 800 1000 Feet

Contour interval 20 feet

Geology by
C. A. Lamey, July-October, 1944

Topography by
U S Bureau of Mines, 1944

EXPLANATION

IGNEOUS ROCKS
(PROBABLY LATE JURASSIC OR EARLY CRETACEOUS)

Dikes, chiefly intermediate to basic in composition

Fine-grained diorite or diabase, perhaps younger than the quartz diorite

Quartz diorite

Diorite, in part epidotized and contaminated; a contact facies of the quartz diorite; may include small amounts of iron ore

METAMORPHIC ROCKS
(METAMORPHISM CONTEMPORANEOUS WITH QUARTZ DIORITE)

Marble, (metamorphosed Permian (?) McCloud limestone)

Carbonate-silicate rock; contains much pyroxene

Skarn (garnet-epidote-pyroxene rock)

Mixed skarn and diorite

COVERED

Probably underlain chiefly by skarn and carbonate-silicate rock; includes some diorite and small amounts of iron ore

IRON ORE

Chiefly magnetite

Magnetite and skarn

Magnetite, skarn, and diorite

Covered ore zone, as indicated by magnetic attraction and drilling

MISCELLANEOUS SYMBOLS

Breccia

Shear zone

Vertical shear

Inclined shear

Fault

Strike and dip of bedding

Direction and inclination of prominent joints

Outcrop boundary

Approximate formation boundary

Pit boundary

Projection of diamond drill hole

needle observations were recorded. Observations were taken mainly at 12-foot intervals along traverses over the ore zone; at no place did the intervals exceed 25 feet. For the most part the mapping was done by the writer, unassisted, by means of telescopic alidade and tape, but valuable assistance was given by P. Dean Proctor for a few days at the close of the work.

ACKNOWLEDGMENTS

The writer is indebted to the U. S. Reclamation Service for furnishing transportation across the lake, and to Carrico and Gautier for the release of production data and for courtesies extended during the work.

PREVIOUS PUBLICATIONS

Little has been published about the iron-ore deposits of Shasta County. The most important papers dealing with the deposits and the geology of the surrounding area are listed in the bibliography at the end of this paper. The reference by Whitney deals chiefly with the limestone of the area. The best account of the iron-ore deposits is given by Prescott.

GENERAL GEOLOGY

Rock Formations and General Relations

The succession of rocks exposed in the vicinity of the iron-ore deposits is given below. Only those in italics were definitely identified in the area mapped.

Succession of rocks exposed in the vicinity of the Shasta and California iron-ore deposits, Shasta County, California

	Igneous rocks
Mesozoic (?)	
Post quartz diorite	*Basic, intermediate, and acidic dikes*
Mesozoic	
Late Jurassic or early Cretaceous	*Diorite* (fine-grained, possibly younger than the quartz diorite). *Quartz diorite*
Triassic	Dekkas andesite (flows).
	Sedimentary rocks
Paleozoic	
Permian	Nosoni formation (tuffs, tuffaceous conglomerates, flows, shales, sandstones; some limestone lenses).
Permian (?)	*McCloud limestone* and its metamorphic derivatives and associated iron ore.
Mississippian	Baird formation (tuff, sandstone, and shale).

Neither the Baird nor the Nosoni formations are described, because they are both some distance from the deposits. The Dekkas andesite, however, although apparently not present in the mapped area, is exposed near the deposits and is therefore described along with the formations that are exposed.

The geologic relations are somewhat obscured by overburden and by extensive metamorphism produced by the quartz diorite. In general the ore zone forms a rudely crescentic central belt between the quartz diorite on the southeast and west, and marble and other metamorphic rocks on the northeast (See pls. XVII and XVIII). Along the southeast side of the ore zone the quartz diorite is bordered by a fine-grained dioritic rock thought to be a contact phase of the quartz diorite.

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Igneous Rocks

Quartz Diorite. The quartz diorite exposed at the surface is gray and its texture ranges from coarse to fine grained. Characteristically it is considerably decomposed, because of the oxidation of pyrite, and is reduced to brownish rubble and sand.

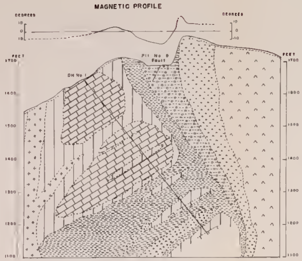
The quartz diorite from drill holes is both fine grained and coarse grained. The coarse-grained type ranges from a light-gray rock containing white plagioclase and a green ferromagnesian mineral to a dark-gray rock containing greenish plagioclase and a dark-green to nearly black ferromagnesian mineral. The plagioclase is considerably more abundant than the ferromagnesian mineral in the lighter-gray types, and the distribution of these minerals gives the rock a spotted or mottled appearance. Quartz may be seen under a hand lens in all of the coarser-grained types, but it is less evident in the dark-gray varieties. Minute specks of pyrite are commonly present. Microscopic examination by Diller [1] indicated that the ferromagnesian mineral is chiefly augite, although some hornblende and biotite may be present, and locally hornblende may dominate. The plagioclase is chiefly andesine, along with some oligoclase.

Green epidote and brown garnet are conspicuous components of some of the quartz diorite. The fine-grained contact diorite, as well as most of the fine-grained dikes that penetrate the ore zone and the metamorphosed limestone or skarn, are somewhat epidotized and garnetized. Both garnet and epidote persist for considerable distances into the coarse-grained quartz diorite. Garnet is visible in the drill core down to a depth of 504 feet in drill hole No. 2, or about 60 feet beyond the contact with the skarn that borders the ore zone (see pl. XVIII). Epidote is present in the same core down to a depth of 566 feet, and epidote-quartz-calcite veins cut the diorite in a few places along the rest of the hole.

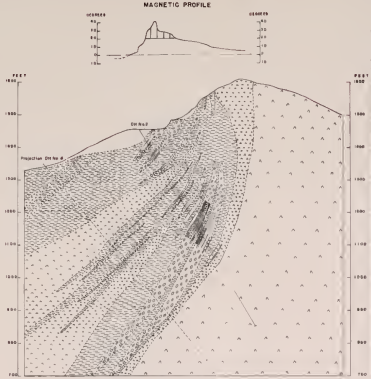
A zone of light-gray to green, fine-grained rock lies between the coarser-grained quartz diorite and the ore and its associated metamorphic rocks. This material is thought to be a contact phase of the quartz diorite. The rock from drill holes that cut this zone is practically the same as the partly epidotized and garnetized diorite dikes through which the drills passed, but the surface material exhibits considerable diversity. Some of it is definitely a contact phase of the quartz diorite and can be traced into that rock. Other parts of it are nearly aphanitic, but a high-powered hand lens discloses numerous small feldspar laths. Some of the feldspar crystals are large enough to be identified as plagioclase. At some exposures these minute feldspars seem to be oriented in a common direction and the rock has a rhyolitic appearance. Characteristically much of the rock in this zone contains small, rather round, greenish spots, and some of it shows the finely granular or sugary texture that is exhibited by many rocks formed by contact metamorphism. In some places these granular rocks are near patches of skarn, which are present in this zone.

Diorite. The rock mapped as diorite is dark gray and fine grained. Plagioclase and pyrite are the only minerals that were recognized under a hand lens. The small plagioclase crystals cause the finer-grained types to have a porphyritic aspect and the coarser-grained ones to appear diabasic. The rock becomes brown on weathering.

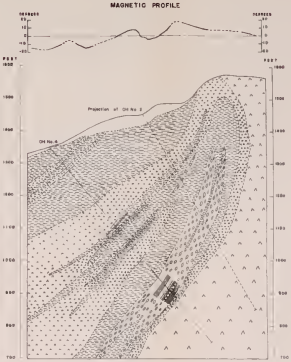
[1] Diller, J. S., U. S. Geol. Survey Geol. Atlas, Redding folio, California (no. 138), p. 9, 1906.



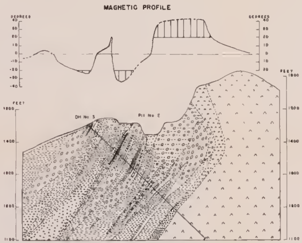
SECTION ALONG LINE A-A', THROUGH DRILL HOLE No. 1



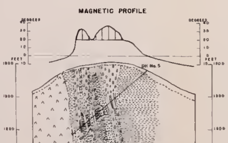
SECTION ALONG LINE B-B', THROUGH DRILL HOLE No. 2



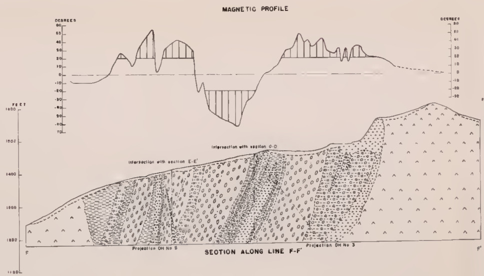
SECTION ALONG LINE C-C', THROUGH DRILL HOLE No. 4



SECTION ALONG LINE D-D', THROUGH DRILL HOLE No. 3



SECTION ALONG LINE E-E',
THROUGH DRILL HOLE No. 5



SECTION ALONG LINE F-F'

EXPLANATION

ORE DEPOSITS

ANALYZED IRON ORE

- More than 50 percent Fe
- 50-60 percent Fe
- 40-50 percent Fe
- 25-40 percent Fe
- Less than 25 percent Fe

UNANALYZED IRON ORE

- Undifferentiated
- Ore and skarn
- Ore, skarn, and diorite

ASSOCIATED ROCKS

- Fine-grained diorite or diabase, perhaps younger than quartz diorite
- Coarse-grained quartz diorite
- Diorite, in part epidotized and contaminated; a contact facies of the quartz diorite
- Skarn (garnet, epidote, pyroxene rock)
- Mixed skarn and diorite
- Carbonate-silicate rock
- Marble

MAGNETIC DATA

- Part of magnetic profile that probably indicates iron ore relatively near the surface (magnetic values higher than +20° or lower than -20°)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BUREAU OF MINES PROJECT 834

SECTIONS AND MAGNETIC PROFILES
SHASTA AND CALIFORNIA IRON-ORE DEPOSITS
SHASTA COUNTY, CALIFORNIA

Scale
0 100 200 300 400 Feet

Geology and magnetic work by
C. A. Lamey, July-October, 1944

Topography by
U. S. Bureau of Mines, 1944

Dike Rocks. Most of the dikes apparently are fine-grained diorite, diabase, or andesite, but a few of them are aplite. The aplite is light pink to nearly white and is composed chiefly of quartz and feldspar. The andesite (?) is light gray but becomes nearly white or very light brown on weathering. It contains rather conspicuous phenocrysts of light-brown to colorless feldspar, much of which is plagioclase, and small, irregular particles of some dark-green to nearly black ferromagnesian mineral in an aphanitic groundmass. Most of the diorite or diabase is dark gray and similar to the diorite previously described. Some of these dikes, however, are coarser grained and contain, in addition to well-developed, elongate crystals of plagioclase, numerous roundish light-colored spots that appear to consist of feldspar enclosing small particles of greenish ferromagnesian mineral. On weathered surfaces these spots, as well as the plagioclase crystals, are conspicuously white and soft.

Some of the dikes or dike-like bodies consist of fine-grained serpentinous, micaceous, and chloritic material. Such material also forms borders along some of the dikes that cut the marble in the northeastern part of the area. Apparently this material was formed by hydrothermal action.

Dekkas Andesite. Only the Dekkas andesite exposed near the ore bodies was examined. Most of it is gray and generally somewhat amygdaloidal. Epidote, quartz, and chlorite are the chief minerals in the amygdules, which commonly are completely filled. In some places the epidote forms oval blobs half an inch or more long. Some of the finer-grained andesite contains well-developed phenocrysts of slightly brown plagioclase, and some of it contains conspicuous amounts of pyrite.

Sedimentary Rocks

McCloud Limestone. The true character of the McCloud limestone is not shown in the area mapped, because it has been extensively metamorphosed, but it is well shown in large exposures a short distance to the north, where the limestone is dark to light gray and fine grained, except near local intrusions. In some places it contains irregular beds, lenses, and nodules of chert; at others it is massive. Fossil corals, crinoid stems, and occasionally brachiopods, were noted in the chert and in the thinner-bedded limestone.

Metamorphic Rocks

The metamorphic rocks include marble, carbonate-silicate rock, and skarn. The classification of material is somewhat arbitrary, since all gradations between the different types are present. It is based chiefly on the amount of carbonate and pyroxene present, considerable quantities of both of these being especially characteristic of the carbonate-silicate rock.

Marble. The marble, both in surface exposures and in drill cores, is coarsely crystalline and nearly white or slightly mottled with light gray. The average diameter of the crystals, predominantly calcite, is about a quarter of an inch; the maximum as much as 2 inches. Occasional chert lenses and nodules are still preserved in the marble, but some of the chert has been recrystallized into granular quartz, and some of it, especially near dikes, contains garnet, pyroxene, epidote, and possibly anthophyllite and zoisite or clinozoisite. The development of silicates in the chert apparently began around fossils, as some patches of silicates retain in

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part the outlines of corals. In some places an entire chert nodule has been converted into silicates.

Carbonate-silicate Rock. The carbonate-silicate rock is composed chiefly of white calcite and green pyroxene (probably hedenbergite)[2]; some of it contains garnet and epidote, and perhaps anthophyllite and zoisite or clinozoisite. It ranges from a rock containing considerable amounts of calcite to one composed chiefly of pyroxene with some interstitial calcite. The pyroxene forms aggregates of radiating crystals, some of which attain a length of 6 inches or more. Quartz and small amounts of a dark mineral resembling ilvaite [3] are associated with some of these masses of radiating pyroxene. The quartz characteristically forms an outer border, which separates the pyroxene from the adjacent marble. At the surface these pyroxene crystals are converted into limonite pseudomorphs.

Skarn. The skarn contains large amounts of silicates, associated with which there is some magnetite, pyrite, chalcopyrite, and calcite. The skarn is usually spotted, mottled, or streaked, the characteristic colors being brown, green, and bluish green. Brown garnet and green epidote are usually the dominant minerals but green pyroxene, a bluish-green rather fibrous mineral resembling anthophyllite, and some minerals of the serpentine or chlorite group, are abundant locally; a gray mineral that may be zoisite or clinozoisite is also present in small amounts. A soft, dark-green to greasy brown serpentine (?) is especially abundant in some places, particularly near the magnetite lenses.

Structure

The structure is somewhat obscured by large amounts of overburden and by contact metamorphism, but surface features show that there are two dominant structural trends, one nearly northeast, the other nearly northwest (see pl. XVII). The two major trends are well shown by the joints, shear zones, faults, and dikes. Many of these features are inclined very steeply. Some of them are locally vertical, and throughout their exposed depth may be inclined from the vertical in first one direction and then another. Many of the dikes that cut the marble follow the direction of the major joints. The magnetic map (pl. XIX) also shows clearly the two major trends, and indicates that the northeast direction is the principal one followed by the ore zone.

Stratification in the marble is difficult to detect except at those places where chert beds are present, but the few observations that could be made show a northwest strike and a northeast dip at angles ranging from 45° to 60°. These correspond in general with the strike and dip of the McCloud limestone a short distance to the north.

ECONOMIC GEOLOGY

Ore Deposits

General Relations

The ore deposits consist of irregular lenses of magnetite intercalated between skarn and in some places intimately mixed with it. Most of the lenses are extremely discontinuous, both along their trend and their dip (see pls. XVIII and XIX). It is difficult to determine their con-

[2] Hedenbergite was identified by Prescott, op. cit., Econ. Geology, vol. 3, p. 473, 1908.

[3] Ilvaite was described by Prescott, op. cit., pp 473-474.

FIG. 46. Drilling jackhammer holes in waste-stripping operations. *Photo by John R. Shattuck, U. S. Bureau of Mines.*

FIG. 47. Bureau of Reclamation barge transporting loaded ore trucks across Shasta Lake. *Photo by John R. Shattuck, U. S. Bureau of Mines.*

FIG. 48. Mining and stripping operations on upper bench of pit No. 1. Note rooter drawn behind tractor in foreground. *Photo by John R. Shattuck, U. S. Bureau of Mines.*

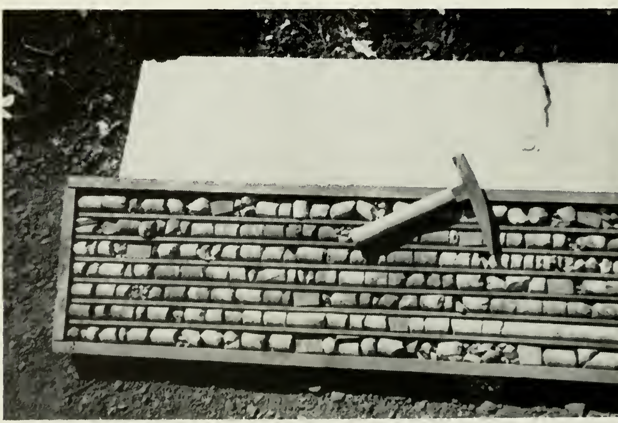

FIG. 49. Typical core from mineralized portion of hole No. 5. Shows distribution of magnetite. *Photo by John R. Shattuck, U. S. Bureau of Mines.*

FIG. 50. Drilling a bench in pit No. 2. Note completed holes covered by rocks.
Photo by John R. Shattuck, U. S. Bureau of Mines.

FIG. 51. Diamond drill set-up at hole No. 4. Stoves for drying sludge in foreground.
Photo by John R. Shattuck, U. S. Bureau of Mines.

FIG. 52. View southwest along strike of mineralized zone from pit No. 6. Pit River bridge and Shasta Lake in distance. *Photo by John R. Shattuck, U. S. Bureau of Mines.*

FIG. 53. Looking northwest along strike of zone from a point between pits Nos. 1 and 2. Limestone exposed in upper left-hand corner of picture. *Photo by John R. Shattuck, U. S. Bureau of Mines.*

tinuity from the poor surface exposures, but drilling and magnetic work show that good ore may be succeeded by very poor material within a few feet.

The magnetic map (pl. XIX) furnishes the best clue to the distribution of the deposits. It is only a general guide, as is shown by the sections (pl. XVIII); nevertheless, it gives a fair idea of the conditions that may be expected, as is well illustrated by the sections through holes Nos. 1, 4, and 5 (pl. XVIII). The almost complete absence of ore in hole No. 1, and the lack of the continuation of the ore from the upper part of hole No. 2 into the area penetrated by hole No. 4 could be anticipated from the magnetic map.[4]

Mineral Composition and Character

The usual ore consists of magnetite, varying amounts of garnet, epidote (pistacite), pyroxene, serpentine or chlorite, and calcite; perhaps also some anthophyllite and zoisite or clinozoisite; small amounts of quartz and ilvaite; and usually a little pyrite, chalcopyrite, and possibly pyrrhotite. Garnet and epidote are especially characteristic. Most of the garnet is probably intermediate between andradite, $Ca_3Fe_2(SiO_4)_3$, and grossularite, $Ca_3Al_2(SiO_4)_3$. A partial chemical analysis of a single sample indicated that it consisted of 91.5 percent andradite and 9.2 percent grossularite.[5] Some of the pyroxene has been identified by Prescott [6] as hedenbergite, $CaFe(SiO_3)_2$, but some of the material noted in drill cores is granular and resembles salite or some other pyroxene intermediate in composition between diopside, $CaMg(SiO_3)_2$, and hedenbergite.

Most of the ore has a granular appearance and is composed of numerous small magnetite crystals in well-formed dodecahedrons or in dodecahedrons modified by octahedrons. In much of the ore these crystals are perfectly outlined or have boundaries that are encroached on but little by those of other crystals.

Some of the ore is nearly free from silicates but contains many small spots of calcite, and some of it is spotted with both silicates and calcite. The silicates commonly occur in streaks showing irregular to somewhat smooth boundaries with the magnetite, and in small masses that appear to be entirely surrounded by magnetite. In some drill cores, fragments of skarn and of marble are very angular and are more abundant than the magnetite, which is present as a filling between the fragments, but in others the fragments appear to have been replaced to some extent by the magnetite. Some of the ore and skarn is cut by later calcite and epidote veins.

Part of the granular magnetite appears to have been fractured and the fractures filled chiefly by carbonate and sulphides, with which some garnet is associated. The carbonate, apparently calcite, is gray to white and has pyrite and chalcopyrite intimately associated with it. Some of the pyrite occurs in well-formed single crystals in the calcite, but much of it forms granular aggregates, blobs, and streaks in the calcite. In some places the sulphides are concentrated near the edges of the calcite veins, and where the veins narrow they pass into thin seams composed

[4] The magnetic map was not available at the time the drilling was done, since the writer did not arrive in the area until after the first three holes had been drilled and the fourth one had been located.

[5] Prescott, Basil, op. cit., p. 473.

[6] Op. cit., p. 473.

chiefly of sulphides. Rarely, veins half an inch wide are composed almost entirely of pyrite and small amounts of chalcopyrite. The garnet associated with the carbonate may be present sparingly or abundantly, even nearly to the exclusion of the carbonate. Much of the garnet is well-crystallized; most of the crystals are small, but dodecahedrons an inch across were noted. Only very small amounts of sulphides are present where garnet is abundant.

Less granular magnetite was noted at a few exposures. At some of these the magnetite is associated only with marble and forms bands from a fraction of an inch to several inches thick parallel to the bedding; it also forms seams cutting across the bedding. In the thicker bands there are parallel streaks of partly replaced carbonate. Adjacent to the magnetite bands, and surrounding small blebs of magnetite in the marble, much of the carbonate is brown.

At some exposures, silicates are associated with the bands of magnetite and marble—well-crystallized garnet in narrow streaks between the magnetite and the marble, and pyroxene in larger bands.

Origin

The evidence from surface exposures and drill holes indicates clearly that the magnetite has replaced the marble along and across the beds and along joints. It also appears to have replaced some of the skarn, and to have filled fractures in both the marble and the skarn. Most of the silicates appear to have formed before or contemporaneously with the magnetite; some of the garnet seems to be the only silicate to have formed later. The sulphides and some calcite were also formed later.

The close association of the ore deposits with the quartz diorite, here as well as at several other places throughout the area, clearly indicates that the ore deposition was an episode in the intrusion of the quartz diorite. The relation of the fine-grained diorite that cuts the marble is not clear, but small magnetite bands replace the marble in the vicinity of this diorite and indicate that at least some of the ore was brought in by it. It may be that this fine-grained diorite is a more basic differentiate of the quartz diorite, and is genetically connected with the period of mineralization.

Most of the silicates associated with the magnetite are clearly of contact-metamorphic origin, but their formation must have necessitated the introduction of iron, silica (except where the limestone was cherty), some manganese and chromium, and perhaps also some alumina and magnesia. This is indicated by the chemical analyses in the following table.[7]

No analysis of the epidote from these deposits is given by Prescott. Epidote usually contains much more alumina than any of the minerals listed in the foregoing analyses, the ratio of aluminum to iron commonly being between 6:1 and 3:2. For the ratio 3:1, epidote contains 37.87 percent SiO_2, 24.13 percent Al_2O_3, 12.60 percent Fe_2O_3, 23.51 percent CaO, and 1.89 percent H_2O[8]. Since epidote is abundant, there seems to be no doubt that alumina was introduced.

Reserves

Method of Estimating Reserves

Any estimate of reserves based on only a few drill holes and poor surface exposures can be merely an approximation for deposits known to

[7] Prescott, B., op. cit., pp. 473-477.
[8] Dana, J. D., System of mineralogy, 6th ed., p. 519, 1909.

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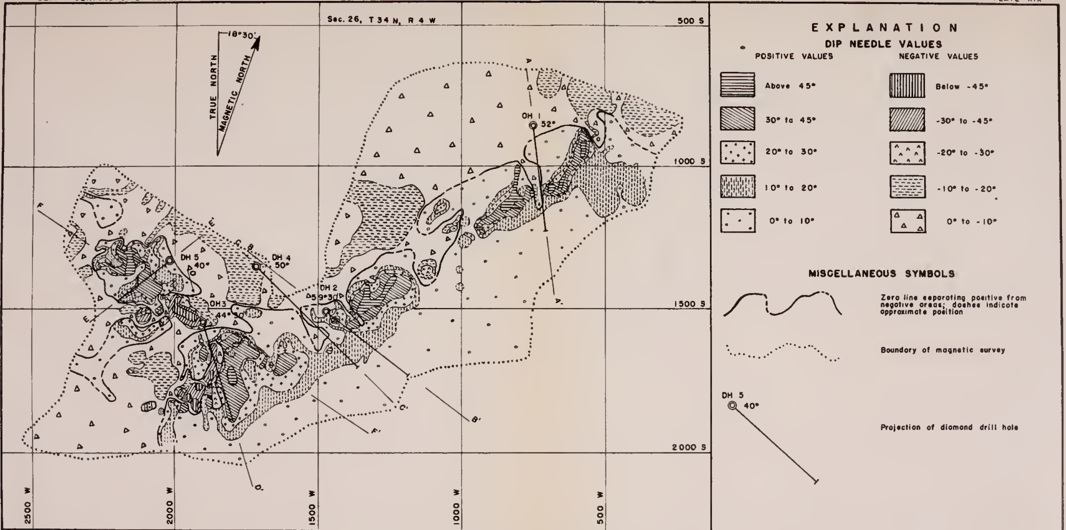
DEPARTMENT OF NATURAL RESOURCES

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE XIX



UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BUREAU OF MINES PROJECT 934

MAGNETIC MAP OF A PART OF THE SHASTA AND CALIFORNIA IRON-ORE DEPOSITS, SHASTA COUNTY, CALIFORNIA

Scale
0 200 400 600 800 1000 Feet

Dip needle observations by C. A. Lamey, July-October, 1944

ACCOMPANYING DIVISION OF MINES BULLETIN 129 K

Chemical analyses of the McCloud limestone and some gangue minerals, Shasta and California iron-ore deposits, Shasta County, California

Constituent	McCloud limestone	Garnet	Hedenbergite	Ilvaite
SiO_2	1.2	35.7	46.4	28.09
Al_2O_3	0.5	2.2	0.6	0.32
FeO	0.2	---	22.6	29.93
Fe_2O_3	---	28.8	---	20.80
MnO	---	---	7.9	3.24
Cr_2O_3	---	---	---	0.13
MgO	1.1	---	2.2	0.18
CaO	53.8	34.0	20.5	15.89
Loss	43.3	---	---	---
H_2O	---	---	---	1.62
	100.1	100.7	100.2	100.2

be composed of extremely discontinuous lenses. Both the drilling and the magnetic data were used in the method of compilation that was adopted, because this combination seemed likely to give the best approximation.

The ore zone was divided into blocks, each of which appeared to show conditions similar to those encountered in the drill hole nearest to it. By means of a polar planimeter the proportion of ore and waste rock was determined for each drill-hole section (B-B′ to E-E′, pl. XVIII), and the surface areas were established for the blocks influenced by those sections. Only those areas were measured that were enclosed within magnetic values greater than 20° or less than —20°, except the area containing the two deep lenses cut by drill holes Nos. 2 and 4, because magnetic work indicated that there is unlikely to be much ore near the surface where magnetic values are between 20° and —20°. The surface area for the two deep lenses was determined by using the 10° magnetic value as a boundary.

Magnetic data alone were used to determine the ore reserves near drill hole No. 1. That hole penetrated no ore, but ore was being mined on each side of the hole and magnetic data indicate the presence of a considerable amount of ore in the vicinity of the hole.

Measurements of waste rock within the ore zone penetrated by drill holes Nos. 2 to 5 ranged from 43 to 79 percent. The latter percentage was applied only to a small area surrounding the upper part of drill hole No. 2, because magnetic data indicate that to the northeast, beyond the projecting tongue of low magnetic values (see pl. XIX), there is much more ore. The average amount of waste rock is about 50 percent, and this figure was used for the area northeast of this projecting tongue as well as for the area around drill hole No. 1, which penetrated no ore.

Estimates of the depth of ore vary with the conditions shown by the drilling. As the Shasta dam may cause flooding to an altitude of 1,070 feet, the depth was not estimated below an altitude of 1,100 feet, except in the two deep lenses; these were estimated to an altitude of 700 feet because analyses show them to be of better grade than most of the ore.

A factor of 9 cubic feet per ton of ore was used to estimate the reserves. This factor was established by the U. S. Bureau of Mines, and the Geological Survey adopted it without making independent specific gravity determinations.

Chemical analyses of the McCloud limestone and some gangue minerals, Shasta and California iron-ore deposits, Shasta County, California

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SiO_2	1.2	35.7	46.4	28.09
Al_2O_3	0.5	2.2	0.6	0.32
FeO	0.2	---	22.6	29.93
Fe_2O_3	---	28.8	---	20.80
MnO	---	---	7.9	3.24
Cr_2O_3	---	---	---	0.13
MgO	1.1	---	2.2	0.18
CaO	53.8	34.0	20.5	15.89
Loss	43.3	---	---	---
H_2O	---	---	---	1.62
	100.1	100.7	100.2	100.2

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A factor of 9 cubic feet per ton of ore was used to estimate the reserves. This factor was established by the U. S. Bureau of Mines, and the Geological Survey adopted it without making independent specific gravity determinations.

Total Amount of Ore

The total amount of ore estimated by the Geological Survey, down to the altitudes shown, is given in the accompanying table. All of the ore has been classed as "indicated," because of the conditions shown by exploratory and magnetic work.

Estimated reserves of indicated iron ore, Shasta and California iron-ore deposits, Shasta County, California

Drill hole number	Estimated percent of waste rock	Lower altitude to which ore was calculated (feet)	Ore (tons)
1	50	1,300	671,000
2	50	1,100	764,000
	79	1,100	50,000
	43	700 *	640,000
3	57	1,150	1,217,000
4	43	700 *	726,000
5	48	1,150	612,000
Total			4,680,000

* Deep lens.

Composition

Analyses for iron were made by the Bureau of Mines from individual core and sludge samples, but analyses for SiO_2, S, P, and Mn were made only of composites from part of the drill-hole material, chiefly from the better grades of ore. Individual analyses for all of these constituents were made from 10 surface samples by the Bureau of Mines.

The average composition of the drill-core samples that were analyzed for the five components noted is shown in the following table, as well as the average iron content of all drill-core samples. Detailed analyses of iron content of individual samples are given in the appendix.

Chemical composition of composite samples of the iron ore by holes, Shasta and California iron-ore deposits, Shasta County, California

Drill hole number	* Feet analyzed	Composition, percent				
		Fe	SiO_2	S	P	Mn
2	129	42.94	11.85	0.15	0.001	0.27
3	71	39.32	14.48	0.42	0.027	0.27
4	87	45.33	11.84	0.094	0.018	0.35
5	71	33.01	16.05	0.065	0.021	0.19
Average for total of 357 feet [a]		40.82	13.24	0.173	0.014	0.273
Average for grand total of 518 feet [b] (which includes 90 feet of waste rock)		33.61	----	----	----	----
Average for total of 428 feet (which excludes 90 feet of waste rock)		37.82	----	----	----	----

* Analyses from following footage: Hole No. 2, 45-55, 82-97, 138-148, 239-244, 301-310, 322-366, 371-407; hole No. 3, 120-130, 142-162, 185-201, 206-211, 284-299, 328-333; hole No. 4, 519-606; hole No. 5, 128-162, 196-201, 206-220, 230-235, 240-248, 263-268.

[a] Total footage in 4 composite samples which were analyzed for SiO_2, S, P, and Mn in addition to Fe.

[b] Total footage analyzed for Fe only.

The average content of iron in the usual ore is more than 33.61 percent (the average for the total footage of the 518 feet of material analyzed) because 90 feet of this total averages only 13.54 percent iron and was therefore logged as waste rock and not included in the ore estimates. If this material is omitted, the average iron content shown by

428 feet of drill core is 37.82 percent, which probably is close to the average content of the ore.

A considerable range in composition is shown by the material analyzed. The range for all samples, including 10 from surface exposures, follows.

Range of chemical composition of analyzed samples, Shasta and California iron-ore deposits, Shasta County, California

Component	*Percent*
Fe	4.00 to 63.98
SiO_2	5.69 to 31.62
S	0.010 to 1.840
P	0.001 to 0.027
Mn	0.19 to 0.67

Grades of Ore

The extreme variation of material within short distances precludes more than a rough approximation of the reserves of ore of different grades. The best guide appears to be the percentage distribution of iron within various ranges in the samples analyzed from drill cores. The following tables have been computed on this basis, but the 90 feet of material that has an average iron content of but 13.54 percent was omitted in determining the percentages and grades.

Estimated reserves of various grades of iron ore, Shasta and California iron-ore deposits, Shasta County, California

Range of iron content, percent	*Average iron content, percent*	*Feet analyzed*	*Percent of total feet analyzed*	*Tons*
13.77–25	20.74	72	16.8	787,000
25 –40	32.94	187	43.7	2,045,000
40 –50	44.78	80	18.7	875,000
50 –60	53.93	72	16.8	786,000
60 –63.98	62.99	17	4.0	187,000
13.77–63.98	37.82	428	100.0	4,680,000

Estimated reserves of iron ore of various cut-off grades, Shasta and California iron-ore deposits, Shasta County, California

Iron cut-off, percent	*Average iron content, percent*	*Percent of total feet analyzed*	*Tons*
13.77	37.82	100.0	4,680,000
25.0	41.28	83.2	3,894,000
40.0	50.50	39.5	1,849,000
50.0	55.66	20.8	973,000
60.0	62.99	4.0	187,000

BIBLIOGRAPHY

Whitney, Josiah Dwight

65 Geological survey of California, vol. 1, Geology, pp. 326-329, 1865.

Fairbanks, Harold Wellman

93 Geology and mineralogy of Shasta County: California Min. Bur. Rept. 11, pp. 35-38, 1893.

Hodson, William G.

93 Shasta County: California Min. Bur. Rept. 11, p. 396, 1893.

Diller, Joseph Silas

03 Iron ores of the Redding quadrangle, California: U. S. Geol. Survey Bull. 213, pp. 219-220, 1903.

06 U. S. Geol. Survey Geol. Atlas, Redding folio (no. 138), 14 pp., map.

Aubury, Lewis E.

06 The structural and industrial materials of California: California Min. Bur. Bull. 38, pp. 301-304, 1906.

Prescott, Basil

08 The occurrence and genesis of the magnetite ores of Shasta County, California: Econ. Geology, vol. 3, pp. 465-480, 1908.

Logan, Clarence A.

26a Sacramento field division—Shasta County: California Min. Bur. Rept. 22, p. 192, 1926.

APPENDIX: DRILL HOLE LOGS AND CHEMICAL DATA

Diamond Drill Hole No. 1

Location: S 858.6; W. 744.7 — Bearing: S 7° 55′ 30″ E
Elevation of collar: 1,648.3 feet — Dip: —52°

Footage	*Feet*	*Material*
0 - 72	72	White, coarsely crystalline marble; a few thin magnetite seams along joints.
72 - 73	1	Brown to greenish-gray metamorphosed limestone; includes some fine-grained diorite.
73 -139	66	White, coarsely crystalline marble.
139 -140	1	Brownish marble containing a few magnetite crystals.
140 -141.5	1.5	White, coarsely crystalline marble.
141.5-143	1.5	Carbonate-silicate rock, streaked white, gray, brown, and black; contorted, in part; contains much coarsely crystalline calcite, some garnet, serpentine (?), quartz, magnetite, pyrite, chalcopyrite.
143 -152.4	9.4	White, coarsely crystalline marble.
152.4-153.6	1.2	Carbonate-silicate rock; contains partly serpentinized pyroxene (hedenbergite ?), yellow-brown garnet, magnetite, pyrite, chalcopyrite, quartz, calcite.
153.6-161	7.4	White, coarsely crystalline marble.
161 -175	14	Carbonate-silicate rock; contains calcite, pyroxene (hedenbergite ?), some of it partly serpentinized, epidote, magnetite, pyrite, chalcopyrite, quartz; small amount of nearly pure marble about 169 and 175 feet.
175 -176.5	1.5	White marble containing small amounts of magnetite.
176.5-195	18.5	Chiefly carbonate-silicate rock composed of calcite, much hedenbergite (?), some epidote, small amount of magnetite; nearly pure white marble, 180-180.4 and 186-187 feet.
195 -292	97	Chiefly white marble; small amount of hedenbergite (?).
292 -300	8	Soft, light greenish to gray sheared and much altered rock composed chiefly of serpentine or perhaps chlorite; perhaps altered carbonate-silicate rock; few inches at bottom is firmer, has quartzitic appearance, and contains considerable fine-grained epidote, perhaps some magnetite.
300 -307.5	7.5	Carbonate-silicate rock; light green, mottled and streaked; contains some fine-grained epidote and disseminated magnetite, some serpentine.
307.5-309.5	2	Carbonate-silicate rock; contains much coarsely crystalline calcite, some hedenbergite (?), specular hematite, perhaps some magnetite, and specks of earthy hematite.
309.5-363	53.5	Nearly white to light-gray medium to coarsely crystalline marble; bottom foot mottled and streaked with small amounts of magnetite; passes into carbonate-silicate rock in the last inch of the core.
363 -374	11	Carbonate-silicate rock; contains coarsely crystalline calcite, hedenbergite (?) (part of it altered to hematite), green epidote, some brown garnet, some pyrite and magnetite.

Diamond Drill Hole No. 1—Continued

Footage	*Feet*	*Material*
374 -399	25	Skarn; composed chiefly of green epidote and brown garnet; some of it chiefly epidote (379-385 feet); some of it chiefly garnet (385-389 feet); some calcite and magnetite, the latter as streaks; much broken, 395-399 feet.
399 -419	20	Carbonate-silicate rock; streaked, mottled, and spotted white, green, brown, and black; contains calcite, hedenbergite (?) (in part serpentinized and sheared), epidote, and magnetite.
419 -466	47	Skarn; composed chiefly of garnet and epidote; contains some serpentine; considerable pyrite and some chalcopyrite, 426.5-427 feet.
466 -476	10	Fine-grained dense, gray diorite; shows very small feldspar crystals; some epidote skarn associated with it.
476 -497	21	Carbonate-silicate rock and white marble; contains hedenbergite (?), epidote, serpentine (?); brecciated, 492-495 feet.
497 -507	10	Chiefly marble; white, streaked, mottled.
507 -538	31	Chiefly skarn; small amount of carbonate-silicate rock at top; much epidote, some garnet and magnetite.
538 -572	34	Fine-grained gray diorite showing small feldspar crystals; partly epidotized in places, contains some garnet; includes a foot or two of garnet-epidote skarn about 560-562 feet.
572 -580	8	Skarn; composed chiefly of epidote and garnet, but contains also some hedenbergite (?), calcite, magnetite, and specular hematite.
580 -597	17	Chiefly carbonate-silicate rock, but contains some marble, 580-584 feet; composed of epidote, garnet, hedenbergite (?), calcite, magnetite.
597 -610	13	White marble; contains some hedenbergite (?) and magnetite.

Diamond Drill Hole No. 2

Location: S 1517.9; W 1466.8 Bearing: S 52° 30′ E
Elevation of collar: 1454 feet Dip: —59° 30′

Footage	*Feet*	*Material*	*Fe, percent*
0- 33	33	Overburden (fill).	
33- 39	6	Chiefly hedenbergite (?) in elongated and radiating crystals 2 inches or more long; some limonite pseudomorphous after hedenbergite.	
39- 45	6	No core.	
45- 48	3	*IRON ORE	36.18
48- 55	7	IRON ORE	39.60
55- 60	5	Skarn; composed of epidote, garnet, serpentine; contains seams of magnetite up to ½ inch across.	
60- 66	6	IRON ORE	22.80
66- 82	16	Skarn; composed of garnet, epidote, serpentine; much serpentine, 66-72 and 81-82 feet; streaks of magnetite near 72, and 74-75 feet; appears brecciated, 66-72 feet.	
82- 87	5	IRON ORE	29.13
87- 92	5	IRON ORE	44.04
92- 97	5	IRON ORE	45.96
97-100	3	IRON ORE	25.82
100-101	1	Mixed epidote, serpentine, and magnetite; some pyrite and chalcopyrite.	
101-108	7	Skarn, chiefly serpentine and epidote; some magnetite near bottom.	
108-111	3	Skarn; serpentine and epidote; only 0.5 foot of core.	
111-117	6	Mashed skarn composed of serpentine and epidote.	

* All of the iron ore was removed from the core boxes by the Bureau of Mines for analysis before the writer arrived in the area; hence it is not described.

Diamond Drill Hole No. 2—Continued

Footage	*Feet*	*Material*	*Fe, percent*
117-124	7	Poor core recovery; skarn composed of serpentine and epidote; contains some magnetite.	
124-130	6	Only 1 inch of core; apparently schistose serpentine.	
130-133	3	Only 2 inches of core; serpentine-epidote skarn.	
133-138	5	Skarn composed of serpentine and epidote; diorite at bottom?	
138-141	3	IRON ORE	32.45
141-148	7	IRON ORE	22.28
148-153	5	Skarn; epidote, serpentine, some garnet; mashed at bottom.	
153-190	37	Fine-grained gray diorite showing feldspar crystals; in part epidotized and serpentinized (?); very poor core recovery, 166-180 feet.	
190-206	16	Skarn composed of epidote, garnet, serpentine; much mashed serpentine, 192-206 feet; veins of quartz and calcite, 197-204 feet; probable fault zone; poor core recovery.	
206-209	3	Fine-grained altered diorite showing feldspar, garnet, quartz, some green ferromagnesian mineral.	
209-239	30	Skarn composed of epidote, garnet, perhaps anthophyllite; fractured and mashed to 220 feet; poor core recovery to 231 feet; quartz-calcite veins, 231-239 feet.	
239-244	5	IRON ORE	45.55
244-250	6	Skarn composed of garnet, epidote, anthophyllite (?), serpentine; some magnetite.	
250-251	1	Dark-green serpentine; only 0.3 foot of core.	
251-255	4	IRON ORE (?)	16.25
255-275	20	Skarn composed of garnet, epidote, anthophyllite (?), serpentine; considerable pyrite and chalcopyrite, 264-272 feet; mashed, 270-273 feet.	
275-279	4	IRON ORE	21.04
279-286	7	IRON ORE	24.38
286-301	15	Skarn composed of garnet, epidote, anthophyllite (?), serpentine; epidote and serpentine increase in amount near bottom.	
301-310	9	IRON ORE	29.76
310-322	12	Skarn composed of serpentine, epidote, calcite, quartz, garnet; magnetite streaks about 321 feet, overlain by serpentine-garnet rock and underlain by rock composed chiefly of garnet.	
322-329	7	IRON ORE	33.67
329-334	5	IRON ORE	57.30
334-339	5	IRON ORE	50.06
339-344	5	IRON ORE	56.80
344-346	2	IRON ORE	63.98
346-351	5	IRON ORE	63.92
351-356	5	IRON ORE	61.73
356-361	5	IRON ORE	53.36
361-366	5	IRON ORE	26.85
366-371	5	Sheared skarn composed of garnet, epidote, serpentine.	
371-376	5	IRON ORE	45.42
376-381	5	IRON ORE	53.09
381-386	5	IRON ORE	40.39
386-390	4	IRON ORE	43.68
390-395	5	IRON ORE	41.38

Diamond Drill Hole No. 2—Continued

Footage	*Feet*	*Material*	*Fe, percent*
395-397	2	IRON ORE	30.60
397-402	5	IRON ORE	33.36
402-407	5	IRON ORE	30.35
407-414	7	IRON ORE (?)	13.77
414-415	1	Fine-grained partly epidotized diorite.	
415-443	28	Skarn composed of garnet, epidote, anthophyllite (?); small spots of magnetite near 419 feet; sheared and containing quartz-calcite-epidote veins, 419-425 feet; about 1 inch of quartzitic material, probably fine-grained diorite, about 425 feet; brecciated and containing quartz-calcite veins, 425-431 feet.	
443-480	37	Fine-grained diorite, partly epidotized; contains some garnet; some skarn, 451-454 and 475-480 feet.	
480-700	220	Medium- and coarse-grained quartz diorite; contains garnet to 504 feet; some of it partly epidotized in places, especially to 514 feet and very little below 566 feet; cut by some calcite-quartz-epidote veins, 566-700 feet.	

Summary of Chemical Analyses, Diamond Drill Hole No. 2

Range of iron content, percent	*Average iron content, percent*	*Feet analyzed*	*Percent of total feet analyzed*	*Other components, percent* SiO_2	*S*	*P*	*Mn*
13.77-25	20.26	35	22.0	----	----	----	----
25-40	31.96	54	34.0	----	----	----	----
40-50	45.10	34	20.8	----	----	----	----
50-60	54.12	25	15.7	----	----	----	----
60-63.98	63.02	12	7.5	----	----	----	----
13.77-63.98	37.92	160	100.0	----	----	----	----
26.85-63.98	42.94	*129	74.2	11.85	0.15	0.001	0.27

* Footage analyzed in composite sample: 45-55, 82-97, 138-148, 239-244, 301-310, 322-366, 371-407.

Diamond Drill Hole No. 3

Location: S 1558.0; W 1899.1 Bearing: S 18° 51′ E
Elevation of collar: 1456.1 feet Dip: —44° 30′

Footage	*Feet*	*Material*	*Fe, percent*
0- 5	5	*IRON ORE	43.30
5- 10	5	No core.	
10- 15	5	IRON ORE	31.70
15- 17	2	IRON ORE	40.12
17- 20	3	IRON ORE	31.04
20- 22	2	IRON ORE	35.79
22- 30	8	Very poor core recovery; skarn, chiefly garnet, small amount of magnetite.	
30- 41	11	Fine-grained gray diorite, somewhat altered; contains some pyrite or pyrrhotite; mashed and sheared toward bottom, and contains chlorite along shear planes.	
41- 58	17	Four diorite dikes a foot to several feet thick, cutting skarn composed chiefly of garnet, epidote, and anthophyllite; diorite partly epidotized; rock shows gradations between skarn and diorite.	

* All of the iron ore was removed from the core boxes by the Bureau of Mines for analysis before the writer arrived in the area; hence it is not described.

Diamond Drill Hole No. 3—Continued

Footage	*Feet*	*Material*	*Fe, percent*
58- 81	23	Gray skarn containing epidote and garnet, some serpentine and chlorite, possibly anthophyllite; probably in part epidotized and altered diorite.	
81-115	34	Fine-grained gray to greenish diorite, partly epidotized and altered to serpentine or chlorite; poor core recovery.	
115-120	5	Chiefly greenish epidote-garnet skarn; some serpentine or chlorite near bottom.	
120-121	1	IRON ORE	34.60
121-125	4	IRON ORE	57.63
125-130	5	IRON ORE	42.88
130-138	8	Epidote-garnet skarn containing stringers and small patches of magnetite (1/16 to 1 inch across); some serpentine, especially near bottom.	
138-142	4	Epidote-serpentine skarn; only about 1 foot of core.	
142-150	8	IRON ORE	22.07
150-157	7	IRON ORE	30.35
157-162	5	IRON ORE	48.32
162-185	23	Chiefly gray-green and brownish epidote-garnet skarn; contains magnetite blobs several inches across in top half-foot and some magnetite stringers and patches in bottom 0.1 foot; probably includes a foot or two of very fine-grained partly epidotized diorite between 164 and 166 feet.	
185-190	5	IRON ORE	50.76
190-195	5	IRON ORE	54.92
195-201	6	IRON ORE	38.04
201-206	5	IRON ORE (?)	17.71
206-211	5	IRON ORE	35.55
211-232	21	Probably is chiefly partly epidotized diorite mixed with epidotite-garnet skarn; contains spots of pyrite or pyrrhotite; has appearance of breccia between 222 and 227 feet.	
232-249	17	Chiefly epidotite skarn containing some garnet and probably considerable anthophyllite (?); some serpentine or chlorite near 239; some magnetite near 249 feet.	
249-256	7	Chiefly gray-brown garnet skarn; some serpentine; about 0.4 foot of magnetite near 251 feet, and 0.25 foot near 255 feet; scattered magnetite spots, 255-255.5 feet.	
256-266	10	Garnet skarn, changing to garnet-epidote skarn about 264 feet.	
266-274	8	Skarn containing some magnetite. Garnet-epidote skarn containing some serpentine to 268.5 feet, followed by about 1 foot of material composed chiefly of magnetite, then by epidote-serpentine skarn containing streaks and patches of magnetite.	
274-284	10	Streaked and mottled epidote-garnet-serpentine skarn; contains some magnetite about 281-282 feet.	
284-289	5	IRON ORE	43.50
289-294	5	IRON ORE	35.96
294-299	5	IRON ORE	34.07
299-306	7	Garnet-serpentine-epidote skarn containing streaks and patches of magnetite.	
306-316	10	Fine-grained partly epidotized diorite containing a small amount of garnet near bottom.	
316-321	5	Much serpentine, some epidote and garnet; may be altered skarn or diorite.	

Diamond Drill Hole No. 3—Continued

Footage	*Feet*	*Material*	*Fe, percent*
321-328	7	Epidote skarn containing some serpentine; considerable serpentine near bottom; probably some fine-grained diorite about 327 feet.	
328-333	5	IRON ORE	29.92
333-334	1	Chiefly magnetite	----
334-346	12	Serpentine-epidote skarn containing some garnet.	
346-356	10	Mottled brown, green, bluish-green garnet skarn containing some epidote and probably considerable anthophyllite (?).	
356-367	11	Greenish garnet-epidote-serpentine skarn.	
367-382	15	Quartz diorite, partly serpentinized (?); contains some garnet.	
382-500	118	Quartz diorite; contains some epidote to 433 feet.	

Summary of Chemical Analyses, Diamond Drill Hole No. 3

Range of iron content, percent	*Average iron content, percent*	*Feet analyzed*	*Percent of total feet analyzed*	*Other components, percent* SiO_2	*S*	*P*	*Mn*
17.71-25	20.39	13	14.0	----	----	----	----
25-40	33.54	44	47.3	----	----	----	----
40-50	44.10	22	23.6	----	----	----	----
50-57.63	54.20	14	15.1	----	----	----	----
17.71-57.63	37.30	93	100.0	----	----	----	----
22.07-57.63	39.32	*71	76.3	14.48	0.42	0.027	0.27

* Footage analyzed in composite sample: 120-130, 142-162, 185-201, 206-211, 284-299, 328-333.

Diamond Drill Hole No. 4

Location: S 1357.7; W 1716.2 — Bearing: S 45° E
Elevation of collar: 1348.0 feet — Dip: —50°

Footage	*Feet*	*Material*	*Fe, percent*
0- 5	5	Overburden.	
5- 30	25	Poor core. Weathered and leached skarn; yellowish-green epidote is chief mineral recognizable.	
30- 38	8	No core.	
38- 50	12	Weathered and leached skarn similar to that between 5 and 30 feet.	
50- 55	5	Weathered and leached skarn; firmer toward bottom, where core shows both calcite and epidote.	
55- 64	9	Chiefly gray, fine-grained diorite; some skarn between 57 and 60 feet.	
64- 76	12	Skarn, mottled green and white, and somewhat leached; contains epidote, garnet, calcite, and some small spots of red, earthy hematite.	
76- 86	10	Unweathered skarn, mottled green and white; contains epidote and calcite, small amounts of hematite.	
86- 94	8	Very fine-grained gray diorite. Practically no core from 91 to 94 feet.	
94-105	11	Green and white mottled and streaked epidote skarn; contains some serpentine and considerable garnet near bottom; poor core, 99-101 feet.	

Diamond Drill Hole No. 4—Continued

Footage	*Feet*	*Material*	*Fe, percent*
105-114	9	Garnet-epidote-serpentine skarn; contains some calcite.	
114-121	7	Greenish-white streaked and mottled epidote-serpentine-calcite skarn.	
121-135	14	Upper part epidote skarn containing calcite, lower part garnet skarn containing pyrite and specular hematite.	
135-145	10	Brownish-white carbonate-silicate rock containing much hedenbergite (?).	
145-180	35	Epidote-calcite-serpentine skarn; contains relatively large amounts of calcite; quartzose and cherty, 179-180 feet.	
180-204	24	Mottled and streaked brown, white, and green garnet, epidote-serpentine-calcite skarn; contains spots of red earthy hematite and some specular hematite.	
204-216	12	Mottled and streaked green and white epidote-serpentine-calcite skarn.	
216-226	10	Brown, green, and white garnet-epidote-serpentine-calcite skarn.	
226-309	83	Fine-grained diorite. Much of it has cherty appearance but contains very small plagioclase crystals; upper and lower parts contain some garnet and epidote, and bottom part intermixed with skarn.	
309-315	6	Epidote-serpentine skarn; contains some spots of red earthy hematite.	
315-318	3	Mixed magnetite and skarn; contains epidote, serpentine, calcite, probably pyroxene, some pyrite	30.09
318-329	11	Garnet-epidote-pyroxene skarn; contains some serpentine and calcite; includes small amounts of fine-grained diorite.	
329-332	3	Fine-grained diorite.	
332-340	8	Epidote-garnet skarn.	
340-344	4	Fine-grained diorite.	
344-378	34	Epidote-garnet skarn.	
378-383	5	Fine-grained diorite.	
383-386	3	Epidote-garnet skarn.	
386-392	6	Fine-grained diorite.	
392-401	9	Epidote-garnet skarn.	
401-445	44	Fine-grained diorite, much epidotized toward bottom.	
445-484	39	Epidote-garnet skarn containing some pyroxene, calcite, and serpentine; much brown garnet in lower part.	
484-486	2	Poor core. Much serpentine.	
486-490	4	Much serpentine; perhaps some fine-grained diorite.	
490-495	5	Epidote-serpentine skarn; some calcite.	
495-506	11	Mixed diorite and garnet-epidote-serpentine skarn.	
506-519	13	Chiefly serpentine; some calcite and some micaceous mineral.	
519-524	5	IRON ORE. Core shows about 80 percent magnetite, rest is calcite, epidote, serpentine	37.74
524-530	6	IRON ORE. Core shows about 60 percent magnetite; gangue minerals are epidote, garnet, serpentine, perhaps pyroxene	38.41
530-535	5	IRON ORE. Core shows only about 20 percent magnetite in epidote-garnet gangue	38.80
535-540	5	IRON ORE. Core chiefly magnetite; some serpentine and garnet	38.14
540-545	5	IRON ORE. Core shows about 75 percent magnetite in gangue of serpentine, epidote, calcite	50.63

Diamond Drill Hole No. 4—Continued

Footage	*Feet*	*Material*	*Fe, percent*
545-548	3	IRON ORE. Core chiefly magnetite; some serpentine, epidote, calcite	54.26
548-553	5	IRON ORE. Core shows about 60 percent magnetite in gangue of serpentine, epidote, calcite	52.83
553-558	5	Core shows only few inches of magnetite and much serpentine and fine-grained diorite	34.39
558-561	3	Core shows about 1 inch of magnetite; rest is serpentine, epidote, some garnet; perhaps some diorite	34.86
561-566	5	Core shows only traces of magnetite; chiefly serpentine, epidote, garnet	37.35
566-571	5	IRON ORE. Core shows about 50 percent magnetite in gangue of serpentine, calcite, epidote	45.28
571-576	5	IRON ORE. Core shows about 75 percent magnetite in gangue of serpentine and epidote	55.83
576-581	5	IRON ORE. Core chiefly magnetite	62.93
581-586	5	IRON ORE. Core shows about 50 percent magnetite in gangue of garnet and calcite	55.59
586-591	5	IRON ORE. Core shows about 75 percent magnetite in gangue of garnet, epidote. and calcite	56.72
591-596	5	IRON ORE. Core shows about 40 percent magnetite in gangue of garnet, serpentine, and calcite	50.15
596-601	5	IRON ORE. Core shows about 40 percent magnetite in gangue of serpentine, calcite, and garnet	47.30
601-606	5	Chiefly garnet, serpentine, and calcite	23.60
606-611	5	Fine-grained gray diorite, partly serpentinized (?).	
611-619	8	Mixed fine-grained and coarse-grained diorite.	
619-780	161	Quartz diorite. Contains some garnet and epidote to 666 feet.	

Summary of Chemical Analyses, Diamond Drill Hole No. 4

Range of iron content, percent	*Average iron content, percent*	*Feet analyzed*	*Percent of total feet analyzed*	*Other components, percent* SiO_2	*S*	*P*	*Mn*
23.60-25	23.60	5	5.6	----	----	----	----
25-40	36.95	37	41.0	----	----	----	----
40-50	46.29	10	11.1	----	----	----	----
50-60	53.68	33	36.7	----	----	----	----
60-62.93	62.93	5	5.6	----	----	----	----
23.60-62.93	44.82	90	100.0	----	----	----	----
23.60-62.93	45.33	*87	96.6	11.84	0.094	0.018	0.35

* Material between 315 and 318 feet omitted from composite analysis.

Diamond Drill Hole No. 5

Location: S 1347.7; W 2023.1 Bearing: S 53° W
Elevation of collar: 1366.3 feet Dip: —40°

Footage	*Feet*	*Material*	*Fe, percent*
0- 10	10	Overburden.	
10- 14	4	Practically no core; few pieces of fine-grained green skarn.	
14- 27	13	No core.	
27- 47	20	Only rounded fragments of core, which show garnet, some epidote, pyroxene or anthophyllite, pyrite, some quartz; small amount of magnetite near bottom.	

Diamond Drill Hole No. 5—Continued

Footage	*Feet*	*Material*	*Fe, percent*
47- 59	12	No core.	
59- 66	7	Probably skarn. Only few rounded fragments of core, which show garnet, epidote, pyroxene (?), quartz.	
66- 69	3	Skarn containing epidote, fibrous anthophyllite (?), much pyrite, some chlorite. Poor core.	
69- 75	6	Poor core. Much dark green serpentine; some magnetite.	
75- 90	15	Epidote-garnet skarn; some serpentine, anthophyllite (?), chlorite, magnetite.	
90- 93	3	Only 1 inch of core; apparently similar to material between 75 and 90 feet.	
93-105	12	Epidote-garnet skarn; contains some pyroxene or anthophyllite, serpentine, quartz; perhaps some fine-grained diorite between 93 and 95 feet.	
105-108	3	Epidote-garnet skarn similar to 93-105 feet but containing more serpentine and some magnetite.	
108-110	2	Chiefly garnet.	
110-113	3	Mottled greenish, bluish, brown, white skarn; contains much garnet, fibrous bluish anthophyllite (?), and a little epidote; some magnetite at bottom.	
113-118	5	Skarn containing epidote, garnet, serpentine, fibrous anthophyllite (?); some magnetite, which appears to replace the skarn	17.22
118-123	5	Light-brown to greenish mottled and streaked skarn; contains much garnet, some fibrous anthophyllite (?), epidote, calcite	16.54
123-128	5	Similar to material between 118 and 123 feet	7.12
128-133	5	IRON ORE. Core shows chiefly magnetite. Some of material has brecciated appearance and contains fragments of garnet and some serpentine; some indication that magnetite may have replaced breccia	45.40
133-138	5	IRON ORE. Core shows about 50 percent magnetite. Material has somewhat brecciated appearance, with remnants of garnet and epidote skarn surrounded by magnetite as if they had been partially replaced. Much quartz and pyrite near bottom, where material is mashed	39.84
138-143	5	Chiefly skarn, but contains about 0.5 foot of magnetite near center of core; contains epidote, garnet, anthophyllite (?), some serpentine; cut by quartz veins and appears to have been fractured and recemented	26.60
143-148	5	IRON ORE. Core appears to contain only about 20 to 25 percent magnetite in skarn similar to that between 138 and 143 feet	40.40
148-153	5	IRON ORE, similar to above	34.70
153-158	5	Mixed skarn and magnetite; much light-green pyroxene (?), showing cleavage plates 0.25 to 0.5 inch across	29.21
158-162	4	IRON ORE. Upper half chiefly magnetite containing some epidote and pyroxene, lower half chiefly skarn containing little magnetite, much garnet, and some light green pyroxene	30.92
162-166	4	Core is chiefly skarn except for about 1 inch of magnetite at the bottom; much garnet, pyroxene (?), some serpentine and epidote	17.05
166-170	4	Upper 3 feet, garnet-epidote-pyroxene skarn containing a few streaks of magnetite near the top; bottom foot, fine-grained diorite	12.59
170-176	6	Fine-grained diorite	
176-181	5	Fine-grained diorite except last 2 inches of core, which is epidote-garnet skarn	10.69

Diamond Drill Hole No. 5—Continued

Footage	*Feet*	*Material*	*Fe, percent*
181-186	5	About 0.5 foot of mixed magnetite and skarn at top; remainder is skarn containing a few streaks of magnetite; gangue minerals are garnet, epidote, pyroxene; one small pyrite vein	15.52
186-191	5	Top foot of core is contaminated diorite containing epidote and garnet; remainder of core is skarn composed of garnet, epidote, pyroxene (?) containing small seams of magnetite	8.14
191-196	5	Chiefly garnet-epidote-pyroxene (?) skarn containing small seams and patches of magnetite	21.35
196-201	5	Material similar to that between 191 and 196 feet	27.09
201-206	5	Garnet-epidote-pyroxene (?) skarn	10.95
206-211	5	IRON ORE. Core appears to contain 50 to 60 percent magnetite in garnet-epidote-pyroxene skarn. Core has brecciated appearance and indicates that ore probably filled fractures and replaced some of the skarn	29.68
211-216	5	IRON ORE. Core shows about 50 to 60 percent magnetite scattered through epidote-garnet-pyroxene (?) skarn	31.55
216-220	4	Very poor core recovery. Material appears similar to that between 211 and 216 feet	22.08
220-225	5	Poor core recovery. Chiefly garnet, mashed and clayey at bottom	15.46
225-230	5	Very poor core recovery. Mixed skarn and magnetite similar to material between 211 and 216 feet, but clayey at bottom (gouge?)	21.00
230-235	5	Core shows about 10 to 15 percent magnetite in epidote-garnet-pyroxene skarn. Silicate minerals appear to have been brecciated and later partly replaced by magnetite. This was followed by later fracturing of the magnetite	26.51
235-240	5	Upper half of core is composed of about 50 percent magnetite, which appears to replace garnet-epidote-pyroxene skarn. After replacement the magnetite and skarn were fractured and those fractures filled with epidote. Lower half of core is garnet-epidote-pyroxene (?) skarn	19.46
240-243	3	Upper 0.4 of core is chiefly magnetite, followed by garnet-epidote skarn to the bottom 0.2 of the core, which is mixed skarn and magnetite	37.71
243-248	5	About 0.4 inch of magnetite at top of core, followed by garnet-pyroxene skarn containing a small amount of magnetite in the upper part. Bottom 0.5 foot of core is fine-grained diorite	26.34
248-253	5	Fine-grained diorite	
253-258	5	Chiefly skarn; contains much garnet and some epidote and pyroxene (?), considerable calcite; a small amount of magnetite near bottom	10.75
258-263	5	Upper $\frac{2}{3}$ of core is chiefly garnet-epidote-pyroxene (?) skarn containing a small amount of magnetite; lower $\frac{1}{3}$ is about 75-80 percent magnetite. Core shows mashing of material before and after formation of magnetite	24.63
263-268	5	IRON ORE. About 85 percent magnetite	46.40
268-273	5	Chiefly skarn; small amount of magnetite at top; broken at bottom	18.66
273-278	5	Upper 0.4 of core appears to contain about 60 percent magnetite in garnet-epidote-pyroxene skarn; remainder of core is skarn	21.13
278-283	5	Chiefly skarn; small amount of magnetite at top	19.39
283-288	5	Chiefly skarn	10.13

Diamond Drill Hole No. 5—Continued

Footage	*Feet*	*Material*	*Fe, percent*
288-293	5	Skarn and serpentine	7.10
293-300	7	Skarn and diorite; core shows about 1 foot of diorite near bottom	5.30

Summary of Chemical Analyses, Diamond Drill Hole No. 5

Range of iron content, percent	*Average iron content, percent*	*Feet analyzed*	*Percent of total feet analyzed*	*Other components, percent* SiO_2	*S*	*P*	*Mn*
5.30-25	14.86	109	61.9	——	——	——	——
25-40	30.66	52	29.6	——	——	——	——
40-46.40	44.06	15	16.5	——	——	——	——
5.30-46.40	22.01	176	100.0	——	——	——	——
22.08-46-40	33.01	*71	40.3	16.05	0.065	0.021	0.19

* Footage analyzed: 128-162, 196-201, 206-220, 230-235, 240-248, 263-268.

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
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DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO
OLAF P. JENKINS, Chief

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Iron Resources of California
Bulletin 129

PART L

Iron-Ore Deposits Near Lake Hawley and Spencer Lakes, Sierra County, California

By Cordell Durrell *and* Paul D. Proctor
Geological Survey, U. S. Department of the Interior

Issued by the
STATE DIVISION OF MINES

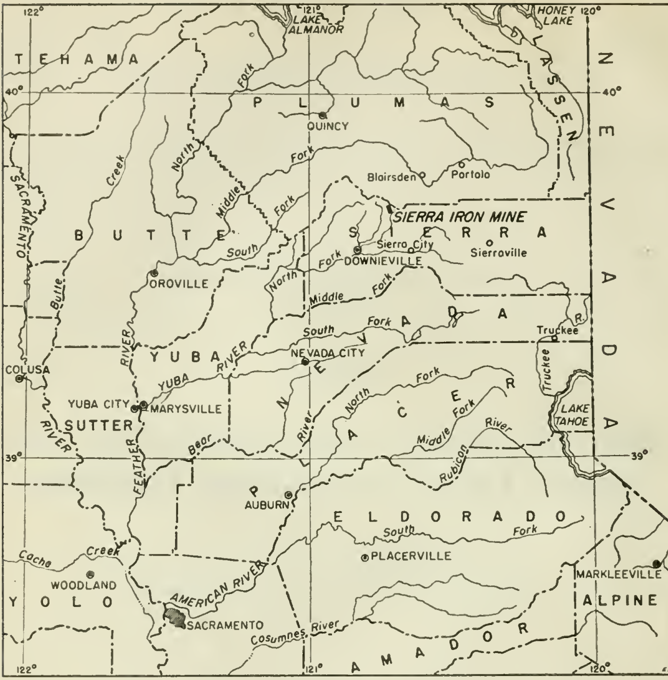

FIGURE 54. Index map showing the location of the Sierra iron mine, Sierra County, California.

IRON-ORE DEPOSITS NEAR LAKE HAWLEY AND SPENCER LAKES, SIERRA COUNTY, CALIFORNIA*

By Cordell Durrell** and Paul D. Proctor**

OUTLINE OF REPORT

ABSTRACT

Deposits of magnetite located in secs. 11 and 14 of T. 21 N., R. 11 E., in Sierra County, California, have long been known. There are two groups of deposits about a mile and a quarter apart, one consisting of 13 small deposits situated near the Spencer Lakes, and the other of three somewhat larger deposits situated about half a mile southeast of Lake Hawley.

All of the deposits are in the Calaveras formation of Carboniferous age, and are believed to be of hydrothermal origin. Most of them consist of magnetite and talc and have apparently originated by the replacement of clastic sediments, tuffs, and lamprophyric dikes. Several of them consist of magnetite and calcite, having replaced dolomite, and two of them are combinations of both types.

The deposits have been dynamothermally metamorphosed and are therefore older than the Nevadan orogeny. They are believed to be genetically related to an intrusion of meta-diorite and its associated dikes.

It is believed that the magnetite-talc rock contains on the average about 30 percent of magnetite, which corresponds to 21 percent iron. The magnetite-calcite rock may contain more iron, but the amount is variable.

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The largest deposit in the Spencer Lakes group is estimated to contain only 3,100 tons of magnetite, and the sum of reserves in all the deposits of that group is estimated to be 8,200 tons of magnetite.

The three deposits of the Lake Hawley group are estimated to contain between 8,900 and 16,700 tons of magnetite per 10 feet of depth, and the total reserves of magnetite are believed to be not greater than 167,000 tons.

INTRODUCTION

Location of the Area

The iron-ore deposits described in this report are in secs. 11 and 14, T. 21 N., R. 11 E., in Sierra County, California, near the divide between the North Fork of the Yuba River and the Middle Fork of the Feather River (fig. 54). The region is shown on the Downieville quadrangle of the U. S. Geological Survey, scale 1:125,000, and on the Sierra City quadrangle of the U. S. Forest Service, a planimetric map on the scale of 1:31,680.

The ore bodies occur in two groups. The northern group is in the west half of section 11, immediately east of Spencer Lakes at elevations of 6,000 to 7,000 feet, and the southern group is in the southeast quarter of section 14, half a mile southeast of Lake Hawley at an elevation of 6,300 to 6,500 feet. All of the deposits except the most northern one apparently fall within a large patented claim known as the Sierra iron mine.

Another deposit is reported to occur near the west shore of Wades Lake in section 2 of the same township, but in Plumas County. It is probably concealed by either brush or talus, for the writers could not find it.

The topography is rugged due partly to glaciation. Parts of the area are perfectly exposed by glacial erosion, but morainal and alluvial deposits covered with brush and timber are abundant, and more or less completely obscure the geology over considerable areas.

The northern deposits at Spencer Lakes can be reached by automobile but only with difficulty. Access is by way of Blairsden and Johnsville via the La Porte road, thence by a very poor private road that serves the Four Hills gold mine which adjoins the northern group of deposits. The deposits below Lake Hawley, about 1¼ miles distant, are accessible from the Four Hills gold mine by way of a good foot trail. Gold Valley, 2 miles below Lake Hawley, may also be reached by automobile over a very poor road from the south end of Gold Lake. The nearest railroad service is at Blairsden on the Western Pacific Railroad.

Aerial photographs of the Tahoe National Forest on a scale of 1:20,000, taken by the U. S. Forest Service include the area, and the general geological map accompanying this report (pl. xx) was made with these photographs as a base.

Previous Work

The geology of the region around the iron deposits is shown in a general way on the Downieville folio of the Geologic Atlas of the United States.[1] The locations of the iron-ore bodies are indicated on the economic geology sheet, but the deposits are only very briefly mentioned in the text.

[1] Turner, Henry W., U. S. Geol. Survey Geol. Atlas, Downieville folio (no. 37), 1897.

The deposits were known at a still earlier time, however, and attracted considerable attention between 1860 and 1880. They are mentioned in numerous summary reports published during that period. Cronise,[2] in 1868, enthusiastically described the deposits as the "excellent ores at Gold Valley, Sierra County, situated under circumstances extremely favorable to large and cheap production" and estimated that a million and a half tons of first-class ore might be recovered from the surface deposits.

Rather long and nearly identical reports on the deposit are given by Raymond [3] and by Putnam [4]; both reports consist largely of quotations from an unpublished report by Clarence King and James D. Hague made in 1873. Putnam's report also includes a quotation supposed to be from a report by Ferdinand, Baron von Richthofen, published privately in 1865 in Virginia City, Nevada,[5] which is, however, almost identical to a part of the quotation from the King and Hague report as quoted by Raymond. That the alleged quotation from the Richthofen report is actually from the King and Hague report is indicated by a quotation in different wording supposedly from the Richthofen report which is included in a brief statement by Hanks.[6] Unfortunately the Richthofen report is not available.

Richthofen, in his report of 1865, as quoted in the several reports mentioned above,[7] estimated the available ore to amount to 1,400,000 tons, averaging 45 to 50 percent of iron. King and Hague, in their report of 1873, estimated the amount of ore in sight at 350,000 to 400,000 tons and believed that the total might be as much as estimated by Richthofen.

Scope of the Present Work

The present report was undertaken as a part of the program of the investigation of strategic minerals by the Geological Survey, U. S. Department of the Interior. The immediate object was the determination of the grade and quantity of ore available. It was imperative to study the geology in the vicinity of the deposits in order that their geologic occurrence could be clearly defined and the probable vertical extent of the deposits be estimated. The present report thus contains a geologic map around the ore bodies, an area of nearly 5 square miles. The area around the Lake Hawley group of deposits was surveyed with a dip needle because of the limited exposures in that vicinity. The results are shown on plate XXII. Detailed geologic sketch maps of most of the ore bodies are included. The bodies that are not shown in detail are omitted either because of their insignificant size or because geologic interpretations were impossible because of brush or nearly complete burial by surficial deposits.

About six weeks in July and August 1945, were devoted to the field work.

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[2] Cronise, T. F., The natural wealth of California, pp. 588-590, San Francisco, 1868.

[3] Raymond, Rossiter W., Statistics of mines and mining for 1875, U. S. Treasury Dept., pp. 44-46, 1874.

[4] Putnam, Bayard T., Notes on the samples of iron ore collected west of the one hundredth meridian: 10th Census, U. S., vol. 15, pp. 493-495, 505, 1886.

[5] Putnam, Bayard T., op. cit., p. 495.

[6] Hanks, H. G., Fourth Report of the State Mineralogist, pp. 236-237, California Min. Bur., 1884.

[7] Putnam, Bayard T., op. cit., p. 494, p. 504; Raymond, Rossiter W., op. cit., p. 45; Hanks, H. G., op. cit., p. 237.

Acknowledgments

The authors are indebted to Dr. Olaf P. Jenkins, Chief of the California State Division of Mines, for use of three analyses of the iron ores. The District Office of the U. S. Forest Service supplied the air photos used as a base for the geological map, and the writers are grateful to the local offices of the U. S. Forest Service for assistance during the fieldwork. Information concerning the patented claim known as the Sierra iron mine was supplied by the U. S. Land Office, Sacramento, California.

GEOLOGY OF THE VICINITY OF THE ORE DEPOSITS

The rocks in the region of the ore deposits are divided into two main groups, frequently referred to in the older literature on the Sierra Nevada, as the "bedrock series," and the "superjacent series." The "bedrock series" includes a wide variety of sedimentary and igneous extrusive and intrusive rocks, all of which are metamorphosed, and younger plutonic intrusive igneous rocks which are not metamorphosed. The latter rocks are the youngest of the "bedrock series" and are generally accepted as Jurassic in age. The "superjacent series" includes various igneous extrusive rocks and sediments of Tertiary and Quaternary age. The "bedrock series" and the "superjacent series" are separated by a profound unconformity.

Rocks of the Region

Calaveras Formation (Carboniferous)

The oldest rocks of the area are metamorphosed sedimentary and igneous rocks belonging to the Calaveras formation.[8] The age of the Calaveras is not determined in the Downieville quadrangle, but is considered to be Carboniferous on the basis of fossils found farther north, west, and south.

Most of the Calaveras formation in the vicinity of the iron-ore deposits consists of low-grade metamorphic rocks derived from fine sandy sediments, from tuffs and tuff breccias largely rhyolitic to dacitic in composition, from mixtures of calcareous and clastic sediments, and from cherts. A few thin beds of metamorphosed conglomerate and of metamorphosed volcanic breccia are present. Prominently outcropping beds of metamorphosed dolomite or dolomitic limestones were separately mapped as they afford almost the only clue to the internal structures of the Calaveras formation. Possibly some metamorphosed lava flows of rhyolitic to dacitic composition are present also.

These rocks have been intensely deformed and recrystallized with the result that stratification is largely lost except in the meta-cherts and meta-dolomites. Cleavage is well developed in the finer meta-sediments and in the meta-pyroclastic rocks but is lacking in the meta-dolomite and the meta-cherts.

The principal rock of the Calaveras formation in the vicinity of Spencer Lakes is appropriately termed meta-sandstone. It is a poorly cleaved rock, derived from fine sandstones and sandy shales, with some coarse gritty sandstone and thin conglomerate beds. The original clastic texture is clearly evident, though the stratification has been mostly

[8] Turner, Henry W., op. cit.

destroyed. Thick lenses of meta-chert containing small calcareous concretions are interbedded with the clastic rocks. The meta-chert occurs mostly in layers from half an inch to 4 inches thick separated by shaly or slaty partings; it is recrystallized but is uncleaved and the bedding is clearly evident.

Sericitic and chloritic slates or phyllites derived from tuffs and tuff breccias of silicic to intermediate composition are abundant east of Spencer Lakes and are the predominant rock south of Lake Hawley. Small fragments and crystals of quartz are abundant. Cleavage is well developed, but the original clastic texture is clearly evident.

The meta-dolomite is a cream to tan, sugary grained rock which is usually massive because of recrystallization. Breccia structures are common. Northwest of Lake Hawley some of the meta-dolomite shows fine bedding and lamination, though the rock as a whole is badly brecciated.

The thickness of the Calaveras formation is unknown but it must be many thousands of feet.

Meta-Rhyolite Series (Permian?)

The term meta-rhyolite series is applied rather loosely to a thick series of rocks overlying the Calaveras formation; they were called quartz porphyry by Turner.[9] For the most part they are light-colored schistose rocks containing abundant large phenocrysts of quartz in a matrix of muscovite and quartz. Massive rocks and breccias are interbedded. It is clear that most of the mass represents extrusive and pyroclastic rocks, though intrusive bodies are very likely included.

The base of the meta-rhyolite series immediately southwest of Wades Lake consists of meta-conglomerate, from 2 to 10 feet thick, that is of local origin. Where the meta-rhyolite series rests on dolomite of the Calaveras formation, the basal conglomerate is composed dominantly of fragments of that rock, and where the meta-rhyolite series rests on other rocks of the Calaveras, as on the west flank of the small syncline southwest of Wades Lake (pl. XX), the basal conglomerate is arkosic. It is clear from this relationship that the meta-rhyolite series is younger than the Calaveras formation and the age is probably Permian.

The thickness of the meta-rhyolite series has not been measured but is estimated to be about 4,000 feet.

Bedded Rocks Younger Than the Meta-Rhyolite Series (Permian?)

A relatively thin sequence of beds consisting of metamorphosed clay shale, siliceous shale, chert, and basic tuff which in some places contains one or two thin flows of basalt overlies the meta-rhyolite series. This sequence, which is not shown on the accompanying maps, is probably in part what was mapped by Turner [10] as siliceous argillite. The thickness of this unit is estimated to vary between 80 and 300 feet.

Overlying the metamorphosed sedimentary beds is an exceedingly thick series of metamorphosed basic lavas and tuffs that was called augite porphyrite by Turner.[11] These rocks, not shown on the accompanying maps, are probably Permian in age.[12]

[9] Turner, Henry W., op. cit.
[10] Turner, Henry W., op. cit.
[11] Turner, Henry W., op. cit.
[12] Wheeler, Harry, *Helicoprion* in the Anthracolithic (late Paleozoic) of Nevada and California and its stratigraphic significance: Jour. Paleontology, vol. 13, pp. 103-114, 1939.

The augite porphyrite is in turn succeeded by the Milton formation[13] of Jurassic (?) age.

Intrusive Igneous Rocks (Permian?)

Several types of igneous rock intrude the Calaveras formation in the vicinity of the magnetite deposits. All are dynamothermally metamorphosed except the quartz monzonite east of Spencer Lakes. All of the intrusions except the quartz monzonite and the diorite immediately south of it are small but are present in great numbers. No attempt was made to show them all on the small-scale maps, but a few are shown to indicate the general relationships.

The relative ages of the several meta-igneous rocks have been in part determined from physical relationships, and in part inferred from the stratigraphic sequence of igneous rocks already described.

Meta-Rhyolite Porphyry. Large numbers of small intrusions of meta-rhyolite porphyry, mostly dikes 10 to 50 feet thick, and short lenticular sills, intrude the Calaveras formation. They are particularly abundant between Lake Hawley and Spencer Lakes. They are most numerous close to the base of the overlying meta-rhyolite series and some may be traced across the contact. Two such bodies in the area north of Lake Hawley are shown on the accompanying geologic map (pl. XX). The intrusive rocks are essentially identical to the more massive phases of the bedded series, though in some the quartz phenocrysts are larger, being as much as three-fourths of an inch in diameter. They undoubtedly represent intrusive phases of the igneous activity that produced the bedded series, and in part they may have been the feeders for the extrusive rocks.

Meta-Augite Andesite Porphyry. A rather large body of meta-augite andesite porphyry is present west of Wades Lake, and two small outcrops of identical rock appear as windows in the morainal deposits in the southwest corner of section 2. Other bodies of similar rock occur elsewhere in the vicinity.

The rock consists of a dense dark-green matrix containing abundant tabular phenocrysts of saussuritized plagioclase feldspar ranging up to $1\frac{1}{2}$ inches in diameter and a quarter of an inch in thickness, and uralitized augite phenocrysts ranging up to three-eighths of an inch in diameter. The rock is nonschistose.

The augite andesite porphyry was not found in contact with the meta-rhyolite porphyry or the meta-rhyolite series. It probably was intruded during the period of igneous activity that produced the basic lavas and tuffs and is therefore believed to be younger than the meta-rhyolite series.

Meta-Diorite and Meta-Diorite Porphyry. Several areas of meta-diorite, all of them parts of the same intrusion, occur immediately east of Spencer Lakes. In addition to this large mass there are innumerable dikes of meta-diorite and closely related meta-diorite porphyry in the area extending south to about half-way between Lake Hawley and the group of magnetite deposits south of the lake. Several of these dikes are shown on the geologic sketch maps (pl. XXIII) of the smaller magnetite deposits in the vicinity of the Spencer Lakes.

The meta-diorite of the large intrusion near Spencer Lakes was a medium-grained hypautomorphic rock containing on the average about

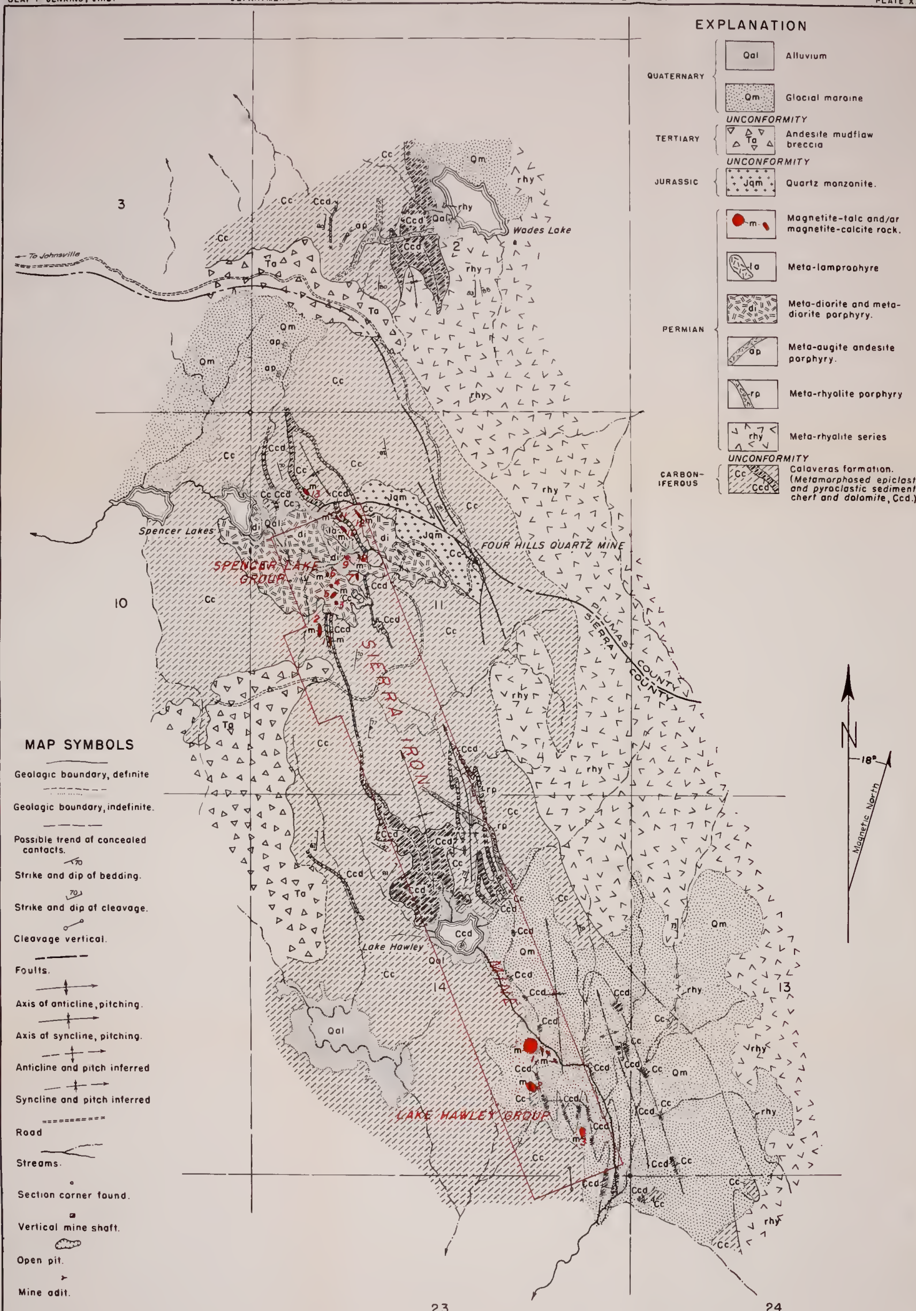
[13] Turner, Henry W., op. cit.

DIVISION OF MINES
OLAF P. JENKINS, CHIEF

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BULLETIN 129-L
PLATE XX



GEOLOGIC MAP OF THE MAGNETITE DEPOSITS
OF THE
SIERRA IRON MINE AREA
SIERRA COUNTY, CALIFORNIA
BY CORDELL DURRELL AND PAUL D. PROCTOR
AUGUST 1945
SCALE
0 1000 2000 3000 4000 FEET

30 percent of dark minerals. Most of the rock is coarsely banded owing to a systematic variation in the content of dark minerals. It was originally composed of calcic plagioclase, augite, hornblende, orthoclase, hypersthene, biotite, and quartz in order of decreasing abundance. The minor accessory minerals include small amounts of allanite, apatite, and magnetite. Metamorphism has resulted in the alteration of augite to fibrous pale-green hornblende; hypersthene to a brown chloritic mineral, and talc; plagioclase to albite, clinozoisite, and sericite; biotite to penninite; and hornblende in part to penninite. Earlier paulopost alteration is indicated by interstitial penninite and epidote, and it is possible that part of the alteration attributed above to metamorphism should be assigned to this stage. The rock is not schistose.

The meta-diorite intrusive is a highly irregular body and its exact form is not readily discernible, for it was probably tilted at the time that the enclosing Calaveras formation was folded and metamorphosed. The body is noticeably elongate across the bedding and schistosity of the Calaveras formation. The irregularity of the contact as it appears on the map is partly due to topography, and probably partly due to the tectonic disturbance. It can only be suggested that the body is an irregular stock that pitches at a moderate to steep angle to the west.

The meta-diorite and meta-diorite porphyry dikes are very similar to the larger intrusions and some are apophyses of it. They are most abundant around the large intrusion east of Spencer Lakes, and also in the area adjoining Lake Hawley on the north and northwest. The abundance of dikes in the latter area may indicate that another large intrusion lies beneath the surface in that vicinity.

The dikes near the margin of the large intrusion are texturally and mineralogically the same as the intrusion. Farther away they are porphyritic with phenocrysts of plagioclase, and of hornblende which is probably uralitized augite for the most part, set in a medium- to fine-grained groundmass. The largest phenocrysts do not exceed half an inch in length.

That the dikes have been dynamothermally metamorphosed is clearly seen from the fact that the smaller ones are cleaved. Cleavage is commonly present only in the marginal part of dikes more than about 10 feet thick.

Meta-diorite dikes have not been found in the meta-rhyolite series though they do cut meta-rhyolite porphyry which is believed to be contemporaneous with the metamorphosed rhyolite flows and tuffs. The meta-diorite and associated dikes are also probably intrusive phases of the basic igneous activity which resulted in the formation of the basic tuffs and flows that succeed the meta-rhyolite series. It has not been possible to find contact relationships between the meta-diorite and the meta-augite andesite porphyry.

Meta-Lamprophyre Dikes. Basic dikes now largely altered by dynamothermal metamorphism to chlorite phyllite are exceedingly common throughout the area. They are the youngest of the metamorphosed igneous rocks, for they are present in the Calaveras formation, the meta-rhyolite series, the metamorphosed basic lavas and tuffs that overlie the meta-rhyolite series, and also in the meta-diorite body, to which they are believed to be genetically related. They are provisionally called meta-lamprophyre, though it is by no means certain that all the dikes so considered are actually the same rock or of the same age. The thickness of the dikes ranges from a fraction of an inch to more

30 percent of dark minerals. Most of the rock is coarsely banded owing to a systematic variation in the content of dark minerals. It was originally composed of calcic plagioclase, augite, hornblende, orthoclase, hypersthene, biotite, and quartz in order of decreasing abundance. The minor accessory minerals include small amounts of allanite, apatite, and magnetite. Metamorphism has resulted in the alteration of augite to fibrous pale-green hornblende; hypersthene to a brown chloritic mineral, and talc; plagioclase to albite, clinozoisite, and sericite; biotite to penninite; and hornblende in part to penninite. Earlier paulopost alteration is indicated by interstitial penninite and epidote, and it is possible that part of the alteration attributed above to metamorphism should be assigned to this stage. The rock is not schistose.

The meta-diorite intrusive is a highly irregular body and its exact form is not readily discernible, for it was probably tilted at the time that the enclosing Calaveras formation was folded and metamorphosed. The body is noticeably elongate across the bedding and schistosity of the Calaveras formation. The irregularity of the contact as it appears on the map is partly due to topography, and probably partly due to the tectonic disturbance. It can only be suggested that the body is an irregular stock that pitches at a moderate to steep angle to the west.

The meta-diorite and meta-diorite porphyry dikes are very similar to the larger intrusions and some are apophyses of it. They are most abundant around the large intrusion east of Spencer Lakes, and also in the area adjoining Lake Hawley on the north and northwest. The abundance of dikes in the latter area may indicate that another large intrusion lies beneath the surface in that vicinity.

The dikes near the margin of the large intrusion are texturally and mineralogically the same as the intrusion. Farther away they are porphyritic with phenocrysts of plagioclase, and of hornblende which is probably uralitized augite for the most part, set in a medium- to fine-grained groundmass. The largest phenocrysts do not exceed half an inch in length.

That the dikes have been dynamothermally metamorphosed is clearly seen from the fact that the smaller ones are cleaved. Cleavage is commonly present only in the marginal part of dikes more than about 10 feet thick.

Meta-diorite dikes have not been found in the meta-rhyolite series though they do cut meta-rhyolite porphyry which is believed to be contemporaneous with the metamorphosed rhyolite flows and tuffs. The meta-diorite and associated dikes are also probably intrusive phases of the basic igneous activity which resulted in the formation of the basic tuffs and flows that succeed the meta-rhyolite series. It has not been possible to find contact relationships between the meta-diorite and the meta-augite andesite porphyry.

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than 20 feet. The dikes can seldom be traced very far because of poor exposures, although one has been followed from well within the large meta-diorite mass into the Calaveras formation on the south, a distance of more than 500 feet. This dike is shown in part on the map of Deposit 5 of the Spencer Lakes group of magnetite deposits (pl. XXIII).

The long dike mentioned above has yielded the least altered sample of the meta-lamprophyre, but it may not be typical as there is reason to suspect that it is somewhat more feldspathic than the average. The freshest material, taken from a point at the south edge of the map of Deposit 5 of the Spencer Lakes group of magnetite deposits, consisted of abundant phenocrysts of augite and sparse phenocrysts of plagioclase set in a fine holocrystalline groundmass of plagioclase and augite. The augite phenocrysts have been altered to uralite, whereas the augite of the groundmass is altered mostly to penninite. The plagioclase, which was probably andesine before alteration, is now an aggregate of oligoclase, zoisite, clinozoisite, and epidote. Sphene and pyrite are present in the groundmass. The texture is typically lamprophyric. In the original rock the light and dark constituents were probably nearly equal in amount. The rock is not schistose. The alterations just described are no doubt the result of metamorphism, as is the more general conversion of lamprophyre to chlorite phyllite. Hydrothermal alteration of the long dike described above is discussed below in connection with the magnetite deposits.

Quartz Monzonite (Jurassic)

A single body of quartz monzonite, which intrudes the Calaveras formation and the diorite previously described, occurs east of Spencer Lakes. The rock is not metamorphosed and doubtless belongs to the plutonic series of Jurassic age.

The quartz monzonite is a light-gray, brown-weathering, medium-grained, hypautomorphic rock composed of oligoclase and microcline in about equal amounts, quartz, and biotite. It is extensively altered even in the freshest specimens obtainable. Plagioclase is largely altered to sericite and epidote, and the original biotite is nearly all changed to penninite. The microcline is partly altered to clay. The alteration is probably related to the formation of the system of auriferous quartz veins that follow the faults in and around the intrusive body as shown on plate XX.

Andesite Mudflow Breccia (Tertiary)

The thick, complex, and extensive sequence of rocks of Tertiary age present elsewhere in the Downieville quadrangle[14] is represented in the area around the magnetite deposits only by andesite mudflow breccias. The breccias are present in two areas only, capping the ridges to the north and to the south of Spencer Lakes. They rest unconformably on the Calaveras formation.

The rocks consist of angular to subrounded blocks of pyroxene and hornblende-pyroxene andesites set in a fine-grained and somewhat clayey matrix of comminuted andesite, and are typical of a very extensive series that extends over the northern and central Sierra Nevada of which they are small remnants. It is generally agreed that they originated as mudflows.[15]

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[14] Turner, Henry W., op. cit.
[15] Lindgren, Waldemar, The Tertiary gravels of the Sierra Nevada: U. S. Geol. Survey Prof. Paper 73, pp. 31-33, 1911.

Glacial Moraines (Quaternary)

Glacial deposits of Quaternary age are spread abundantly over the area, but they do not form well-defined physiographic features. The deposits consist of an unconsolidated jumble of large and small blocks of all the older rocks of the area in a fine gravelly to clayey matrix.

Alluvium (Quaternary)

Alluvial deposits of Quaternary age but younger than the glacial moraines occupy the stream courses and the margins of the lake basins. The deposits range from boulders to peat. The area of alluvium southwest of Lake Hawley is a completely filled lake basin.

Structure of the Region

The structure of the region is extremely complex, particularly within the Calaveras formation where folds of several magnitudes are superimposed. Small faults are present everywhere, and the dynamothermal metamorphism which resulted in cleavage and recrystallization has added further complexities. The attitude of bedding is difficult to determine because of metamorphism. Within the Calaveras formation only meta-dolomite can be separately mapped, and the utility of the meta-dolomite in indicating structure is lessened by the fact that although more than one bed is known to be present, the exact number is not known, and by the fact that the meta-dolomite flowed during metamorphism and is therefore locally absent.

Folding

The rocks of the area generally strike a little west of north and dip steeply to the east. Younger beds are encountered successively for about 5 miles eastward beyond the top of the Calaveras formation.

The contact between the meta-rhyolite series and the Calaveras formation is an unconformity, for the meta-rhyolite series rests on different members of the Calaveras formation, and the conglomerate at the base of the meta-rhyolite series near Wades Lake was derived from that part of the Calaveras formation immediately beneath it. The Calaveras formation therefore was folded before the meta-rhyolite series was deposited. It is difficult to evaluate the intensity of this folding; it was probably not very severe. The Calaveras formation is much more intricately folded than the younger beds, and, although this may be in part a result of the earlier disturbance, it is probably more largely the result of the relatively greater incompetence of the Calaveras formation as compared to the younger rocks when they were later folded together.

The second period of folding, which was much more intense than the earlier one, followed the deposition of all of the stratified members of the "bedrock series", and immediately preceded the intrusion of the quartz monzonite. This was the Nevadan orogeny in the late Jurassic, and was also the time of dynamothermal metamorphism.

Faulting

No faults of large displacement have been observed in the region, but small faults are present in almost every outcrop.

The fault system east of Spencer Lakes contains the auriferous quartz veins of the Four Hills gold mine. This system is younger than the quartz monzonite and is therefore younger than the folding and metamorphism of the stratified members of the bedrock series. The irregularity in the contact of the Calaveras formation with the meta-rhyolite series southeast of Spencer Lakes is probably the result of extensions of the faults shown on the map, though folding may be involved. All contacts in that area are effectively concealed by heavy forest.

No attempt has been made to show the innumerable small faults on the small-scale geologic map (pl. XX) but a few of them are shown on the large-scale maps of the magnetite ore bodies (pls. XXI and XXIII). They cannot be followed for any great distance, and they are seldom accompanied by much brecciation or gouge. They were probably developed during both periods of folding. They are clearly older than the dynamothermal metamorphism, for the gouge along them is recrystallized and the cleavage is continuous through it.

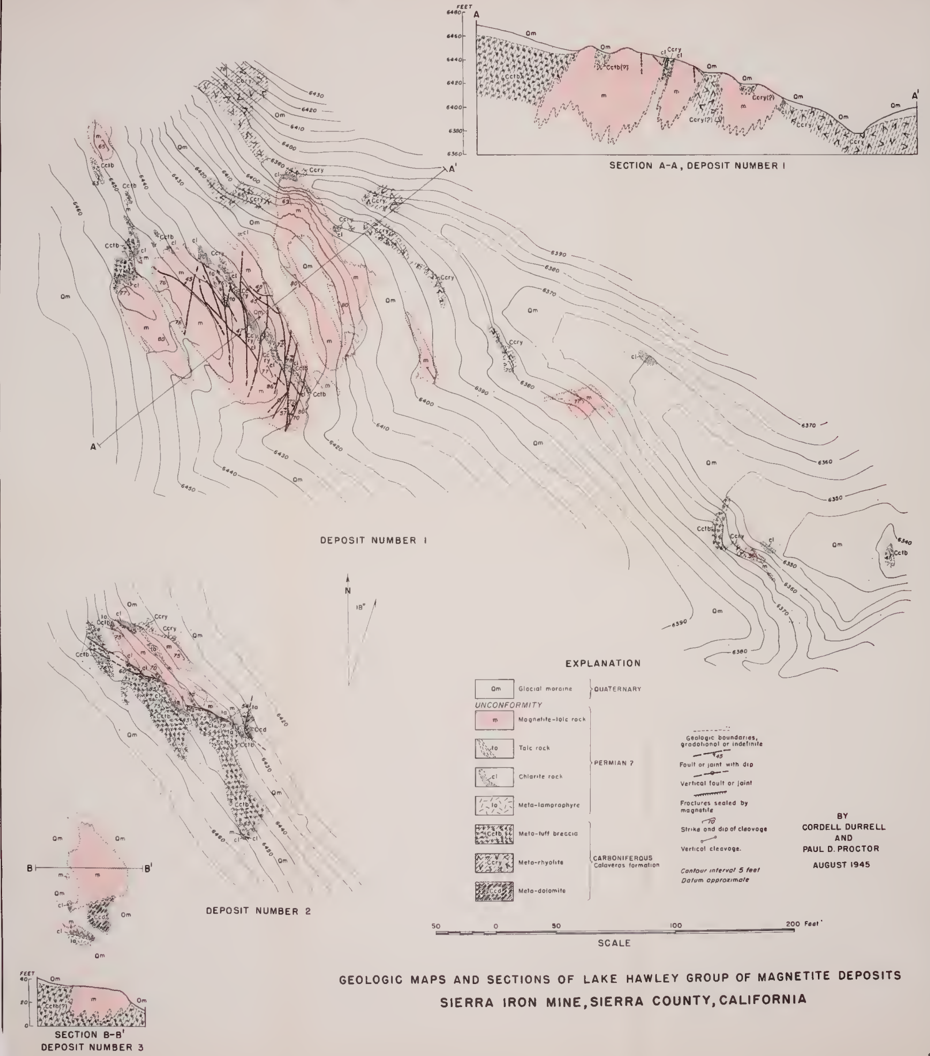
Structural lines which were seen in the aerial photographs of the region and appeared to be faults either were unimportant or could not be found on the ground.

Dynamothermal Metamorphism

All of the rocks of the area except the quartz monzonite and those of Tertiary and Quaternary age have been subjected to dynamothermal metamorphism of low grade. Probably all the metamorphosed rocks are recrystallized, but they are uniformly fine grained. The original texture and structure of many of the rocks are still visible in the hand specimen. The most conspicuous result of the metamorphism is the cleavage.

The cleavage is generally parallel to the predominant northwest strike of the beds. It is by no means uniform, however, and north and northeast strikes are common. The cleavage passes through the axial regions of the folds and is therefore generally discordant with the bedding. It dips west over most of the area but vertical and east dips are present. The lowest measured value of dip was 67 degrees. The cleavage passes through the contact between the Calaveras formation and the meta-rhyolite series and also is present in the younger beds east of the mapped area. It likewise passes through the faults, except the system of the Four Hills gold mine, and enters or passes through most of the intrusive igneous rocks of the area. All of the meta-lamprophyre dikes and the smaller meta-diorite porphyry dikes are cleaved but the interiors of the thicker dikes are massive. The meta-augite andesite porphyry intrusives are thoroughly recrystallized but are uncleaved. Likewise there is no cleavage in the meta-cherts and the meta-dolomite of the Calaveras formation. It is clear in these cases that the more massive and resistant rocks have not assumed a cleavage while associated weak rocks have become perfectly cleaved.

The meta-diorite intrusive east of Spencer Lakes, though recrystallized, is likewise uncleaved. Cleavage is absent also from the Calaveras formation in a zone up to 200 feet in width around the diorite intrusion. Not only was the diorite sufficiently strong to resist the development of the cleavage, but it exerted a protecting effect upon the weak rocks of the Calaveras formation in the region of the contact.



BY
CORDELL DURRELL
AND
PAUL D. PROCTOR
AUGUST 1945

GEOLOGIC MAPS AND SECTIONS OF LAKE HAWLEY GROUP OF MAGNETITE DEPOSITS
SIERRA IRON MINE, SIERRA COUNTY, CALIFORNIA

Contact metamorphism is generally absent. No contact metamorphism has been detected around the quartz monzonite. A mass of wollastonite about 1 foot wide is present in dolomite 300 feet east of Spencer Lakes in the small mass of Calaveras formation which is surrounded by alluvium. The development of the wollastonite is no doubt to be attributed to the diorite, but general contact metamorphism or hornfelsing did not occur. Xenoliths of chert in the diorite have been impregnated with hornblende, and a few masses of hornfels composed of diopside and zoisite, and minor amounts of sphene and talc are also present as xenoliths in the diorite.

GEOLOGY OF THE IRON-ORE DEPOSITS

General Statement

The iron-ore deposits occur in two groups. The northern group, consisting of 13 small areas situated east of Spencer Lakes, is called the Spencer Lakes group of deposits, and the southern group, consisting of three areas located southeast of Lake Hawley, is called the Lake Hawley group of deposits. No magnetite bodies were found between the two groups. All the deposits except one at the north end are apparently within the large patented claim known as the Sierra iron mine. The locations of the deposits are shown on the geologic map, plate XX. They are numbered purely for convenience in describing them.

Geologic sketch maps of most of the deposits of the Spencer Lakes group ore shown on plate XXIII. Those not shown are either of insignificant size or were not well enough exposed to permit mapping. The deposits of the Lake Hawley group are shown on plate XXI. Deposit 3 of this group is shown in a box. Plate XXII is a magnetic map of Deposits 1 and 2 of the Lake Hawley group.

Description of the Magnetite Ore Bodies

The magnetite ore bodies consist of small, irregular to lens-like masses of magnetite and talc, or magnetite and calcite, surrounded by other types of rocks from which they are separated by fractures, faults, previously existing contacts between contrasting rocks, or abrupt gradations. The largest body is roughly 200 by 180 feet in plan. Deposits range in size down to dimensions of about 1 by 4 feet.

The deposits are of two types, depending upon the kind of rock in which they were formed. All of the deposits of the Lake Hawley group and most of those of the Spencer Lakes group consist essentially of talc and magnetite. The surrounding rocks are commonly chloritic and sericitic phyllites derived from tuff and tuff breccia of intermediate to silicic composition, from fine-grained epiclastic sediments, and from lamprophyre. The second type consists of magnetite and calcite, and is found in the dolomite. Two deposits contain both types in combination.

All of the deposits are dynamothermally metamorphosed, and those that contain talc and are located well outside of the meta-diorite intrusion east of Spencer Lakes are schistose.

The Lake Hawley Group of Magnetite Deposits

Deposit 1 of the Lake Hawley group, as shown on the accompanying map (pl. XXI), consists of three main areas of outcrop of magnetite

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rock comprising a body about 200 by 180 feet. There is also a small area of magnetite to the northwest, and three small areas forming a chain to the southeast, extending out about 400 feet from the margin of the large central area.

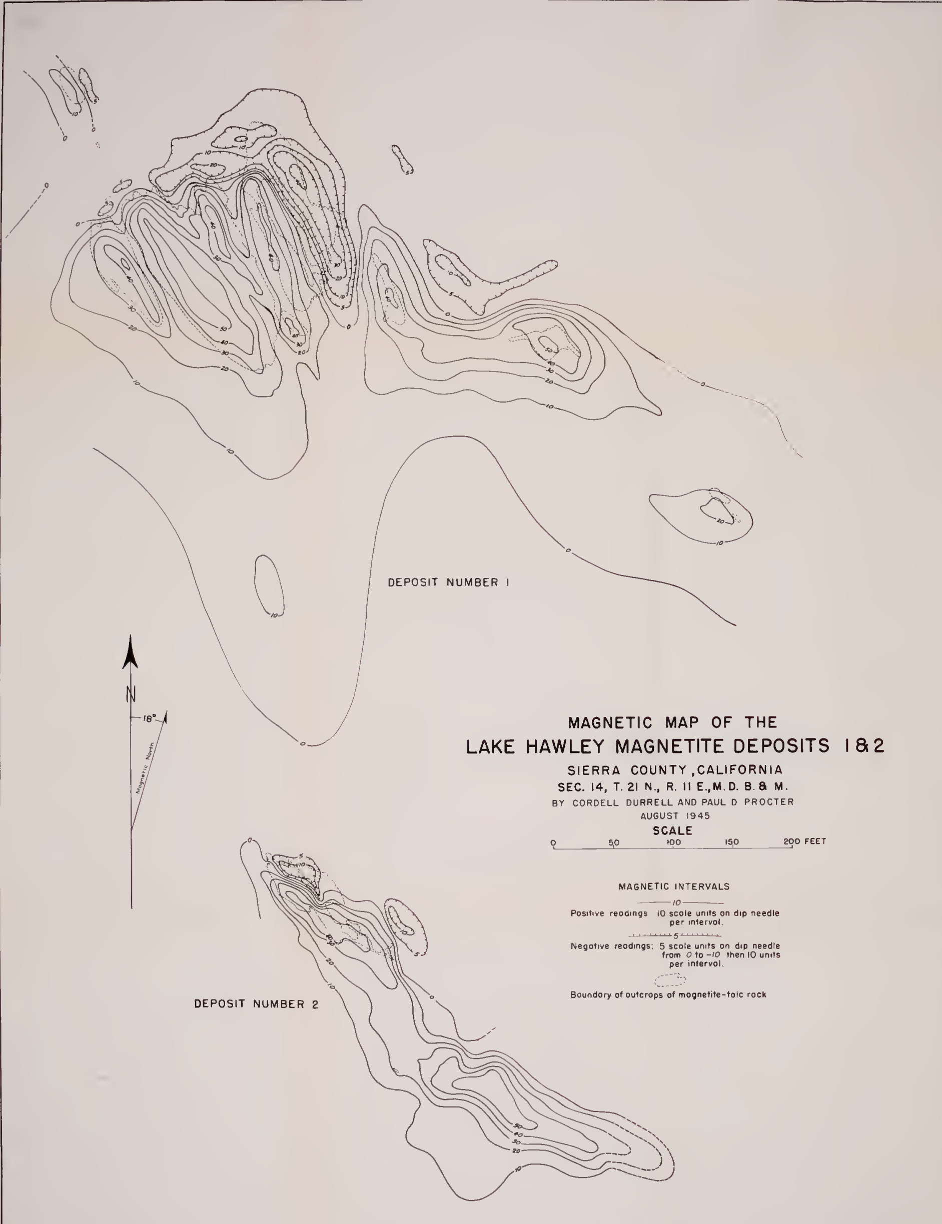
The three component parts of the main area of outcrops are separated by narrow strips of alluvium; in addition, the central one is divided by a septum of metamorphosed rocks. The magnetite rock resisted glacial abrasion and stands out as rounded outcrops above the adjacent morainal deposits and the metamorphosed rocks in contact with it. Though most of the area of bedrock is concealed by moraine, enough of the actual margin of the magnetite is exposed to indicate fairly well the outline of the bodies. It follows from this relationship that the magnetite rock is essentially completely exposed and that no important marginal extensions beneath the moraine are to be expected. This view is confirmed by the magnetic survey of the area made with the dip needle as explained in a following section. It is seen on the magnetic map (pl. XXII) that the intensity of deflection of the needle is decreased by about the same amount where the bordering material is either alluvium or metamorphic rock. Because of this it is believed that the strips of moraine between the three main areas of outcrop conceal septa of metamorphic rocks similar to that which divides the central area. This interpretation is shown on section A—A′, plate XXI.

The magnetite bodies are lenticular in outline, but the details of contacts are highly irregular. An interfingering of the magnetite-talc rock with the wallrocks is the rule. This structural relationship is presumably the result of dynamothermal metamorphism. The bodies are believed to have essentially the same form in section as in plan, as illustrated in section A—A′, plate XXI.

A pattern of fractures is shown in the central area. Similar fractures present elsewhere, which are omitted from the map, undoubtedly have the same significance as those shown. There are two systems of fractures: one striking northwest and dipping northeast; the other striking northward, and dipping both to the east and west. The cleavage direction approximately bisects the acute angle between the two systems. Fractures of the north-trending system offset the septum of metamorphic rock which was undoubtedly once continuous. It is evident that this set of fractures was developed late in the metamorphism, or following it, and cannot be related to the earlier episode of mineralization.

An exceptional fracture near the south end is shown by a separate pattern on the map. This feature is not an open joint as are the other fractures but is a "sealed fracture" 1 to 2 inches thick and filled with granular magnetite and talc. Banding in the magnetite, which is described below, is offset along this fracture, but the cleavage passes through it. The fracture may have existed at the time of mineralization, but the fact that the banding, which is shown below to be premetamorphic, is offset indicates that it was probably developed in an early stage of the tectonic disturbance that culminated in metamorphism.

The rocks surrounding Deposit 1 are meta-tuff breccia, probably originally dacitic in composition, and meta-rhyolites that were probably tuffs. These rocks are in actual contact with the magnetite-talc rock only very locally, and are usually separated from the latter by chlorite rock which varies in thickness from a few inches to several feet. This relationship is described fully below in connection with Deposit 2. It is evident


DEPOSIT NUMBER 1
DEPOSIT NUMBER 2
N
18°
Magnetic North
MAGNETIC MAP OF THE
LAKE HAWLEY MAGNETITE DEPOSITS 1 & 2
SIERRA COUNTY, CALIFORNIA
SEC. 14, T. 21 N., R. 11 E., M. D. B. & M.
BY CORDELL DURRELL AND PAUL D PROCTER
AUGUST 1945
SCALE
0 50 100 150 200 FEET
MAGNETIC INTERVALS
Positive readings 10 scale units on dip needle per interval.
Negative readings: 5 scale units on dip needle from 0 to -10 then 10 units per interval.
Boundary of outcrops of magnetite-talc rock

that both the chlorite rock and the magnetite-talc rock are alteration products of the surrounding metamorphosed pyroclastic rocks.

Deposit 2, which lies 400 feet south of the main body of Deposit 1, is essentially similar to the latter in all respects. The outcrop area of the body is approximately 135 by 40 feet, and is elongate in a northwest direction. Only one other outcrop of magnetite is present here—located at the south end of the area of bedrock—and it is only 1 foot wide and 6 feet long.

The larger body of magnetite-talc rock is lenticular, like those of Deposit 1, and shows the same interfingering at the margin along the north side. The southern margin is different, however, in that it is a northwest-trending system of fractures that are vertical or dip to the southwest. The magnetite does not cross this fracture system, but the chlorite rock which is derived by alteration of the surrounding mass of metamorphosed tuff breccia is present on both sides of the fractures and is localized by them. Talc rock is also associated with the magnetite-talc rock and the chlorite rock, and usually occurs between the two. Talc rock occurs within the magnetite-talc rock, as it does also in Deposit 1, and is also present on the south side of the fracture system, where it is separated from the schistose country rock by chlorite rock.

A detail of this relationship is shown in figure 55 which illustrates a small area at the north end of Deposit 2. In figure 55 the uppermost area of magnetite-talc rock is a part of the main body. A smaller area below it is completely surrounded by talc rock. The talc rock is everywhere surrounded by chlorite rock, and the chlorite rock in turn surrounds a remnant of the meta-tuff breccia shown in the lower right-hand corner of the illustration. This relationship leaves little doubt that the chlorite rock, the talc rock, and the magnetite-talc represent successive stages in the alteration of the tuff breccia and rhyolite. That this is true of the chlorite rock and magnetite-talc rock is also clear at Deposit 1 from the relationships around the septum through the central outcrop of the main body.

It is apparent from the relationships described above that the fracture system which bounds the magnetite-talc rock was a controlling structure in the localization of the deposit. The fracture at the southeast end passes into a fault which brings meta-dolomite into contact with meta-tuff breccia. A little magnetite and chlorite are present in irregular stringers along the fault and in the meta-dolomite. This fact supports the view stated above.

The relation between the chlorite rock and meta-tuff breccia can be seen also under the microscope. The meta-tuff breccia consists of fragments of dacitic rock up to 6 inches in diameter in a matrix of tuff. The rock fragments, which originally had intersertal or intergranular texture, are now composed of laths of plagioclase (An_{10}) in a matrix of light-green chlorite containing some quartz. The matrix of the meta-tuff breccia consists of crystals of quartz and plagioclase (An_{12}) in fine-grained light-green chlorite. Sericite is present along surfaces of shearing. Epidote and calcite are present in tiny crosscutting veinlets. A few grains of zoisite are present and there are a few crystals of magnetite. Leucoxene is abundant.

The chlorite rock derived from the tuff breccia consists of fine-grained chlorite, probably penninite, that polarizes in strong ultra-brown colors and has negative elongation. A little leucoxene and scattered grains of quartz are the only other minerals present.

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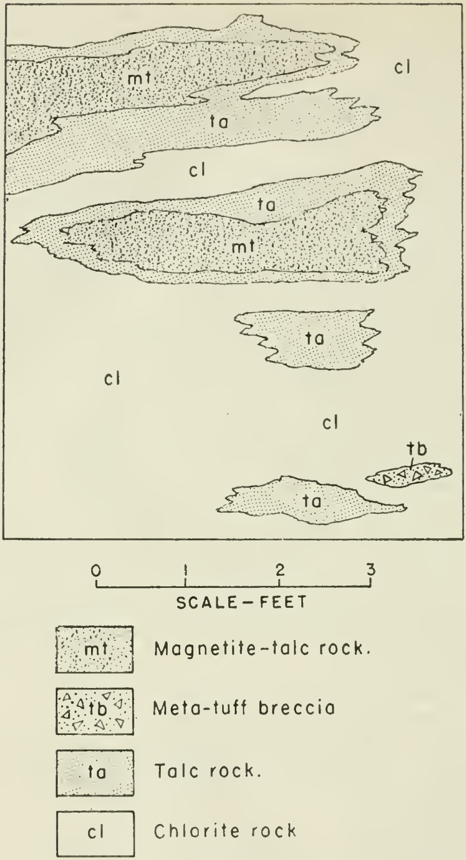

Figure 55. Details of relationship of meta-tuff breccia to magnetite-talc rock.

The chlorite rock and the tuff breccia can be seen to interfinger at the contact, but the transition from one to the other is very sharp and occurs usually within a distance of less than a millimeter. Under the microscope it is seen that alteration to chlorite has proceeded along minute fractures, and that the transition is sharp even at high magnifications. The transitions from chlorite rocks to talc rock and from talc rock to talc-magnetite rock are also very sharp.

The cleavage passes indiscriminately through all of the several rocks and through the fracture system along the south side of the body; it is therefore clearly later than the mineralization.

The magnetite-talc rock of all three deposits of the Lake Hawley group is banded in a most spectacular way as shown in figure 56. In their most perfect development the bands are in sets of three which grade into one another. One outer part of a set consists of a black band of fine magnetite and talc. Adjacent to this is a band of coarse magnetite and talc. The transition occurs by increase in grain size of the magnetite which is as much as a hundred fold. The third band, which forms the other outer margin of the triad, consists of pure or nearly pure talc. The contact between the pure talc of one set and the black band of the next set is exceedingly sharp. These features are illustrated in figure 57*a* drawn from a hand specimen.

Less completely developed sets consist of alternations of black bands of fine magnetite and talc with lighter bands of coarse magnetite and talc. Contacts between sets are always sharper than the intervening contacts. Still less perfect sets consist of streaky alterations of talc and magnetite or magnetite with more or less talc in adjacent bands. The sets of bands vary in thickness from about an eighth of an inch to 2 inches. The component parts are approximately of equal thickness. The most striking feature of the banding is the rhythmic variation in the size of magnetite crystals.

The banding has been folded most intricately and in part irregularly. The amplitude of the folds, which have sharp crests and troughs, varies from 1 or 2 inches to several feet. The surface of the outcrop is thus "grained," as shown in figure 56. The banding persists almost to the margins of the bodies. At exposed contacts there is usually only from 1 to 6 inches of dark-colored, fine-grained, unbanded magnetite-talc rock on the margin. The bands merely fade out. In one unusual specimen, unfortunately not found in place, magnetite-talc rock is in contact with only slightly chloritized tuff breccia. The sets of bands consist of alternations of fine- and coarse-grained magnetite in talc; there is a distinctly higher proportion of talc with the coarse-grained magnetite than with the fine. Each pair is about an inch thick. The bands are nearly normal to the contact surface. The magnetite-talc rock along the contact is fine grained and dark colored for a thickness of about half an inch. The transition from banded to unbanded rock takes place by a gradual narrowing of the bands containing coarser-grained magnetite that starts about 1½ inches from the contact.

There is no structure in the wallrocks, either in the talc rock, the chlorite rock, or the metamorphosed tuffs and breccias, comparable to this banding. It is entirely confined to the magnetite-talc rock, and so far as can be determined it does not reflect any pre-existing structure. The cleavage passes through the bands and through the folds in them, and is therefore clearly later than the bands.

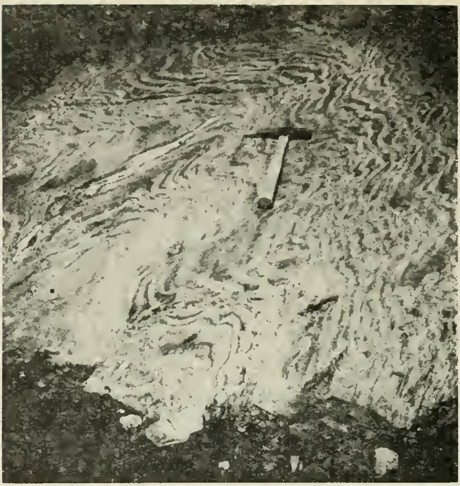

FIGURE 56. Banding in the magnetite-talc rock of Deposit 1, Lake Hawley group of deposits.

Under the microscope the magnetite-talc rock is seen to consist almost entirely of these two minerals. In a few slides shreds and small lenticular relicts of chlorite can be seen. An unidentified colorless mineral, possibly apatite, is present in one specimen. Pyrite occurs here and there, mostly in veinlets of quartz, which indicates that it is probably related to the post-metamorphic episode of gold mineralization. The banded structures are as described above. The magnetite grains are mostly irregular; good crystals are rare. Large grains of magnetite seem most often to be aggregates rather than single crystal units. Most of the irregularity of the grains is the result of crushing. The rupture of a single large grain is illustrated in figure 57*b*. The fractures generally are transverse to the schistosity and divide the original grain into roughly tabular plates. This process of rupture is responsible for the occurrence of much of the magnetite in all specimens as roughly tabular plates that are elongated transverse to the cleavage, as shown in figure 57*c*.

A further effect of dynamothermal metamorphism is the development of pressure shadows[16] of coarse talc about large grains of magnetite as shown in figures 57*b* and 57*d*. The grain size of the talc in the pressure shadows is from 100 to 1,000 times greater than that of the matrix of the rock.

The cleavage in the talc is marked both by good orientation of fine flakes of talc and by lines of shearing, but much of the talc between the shear lines is not oriented parallel to the cleavage.

It is evident from these textural features that the magnetite-talc rock has been dynamothermally metamorphosed, and that during the metamorphism, there was a general reduction of the grain size of the

[16] Pabst, Adolf, Pressure shadows and the measurement of orientation of minerals in rocks: Am. Mineralogist, vol. 16, pp. 55-70, 1931.

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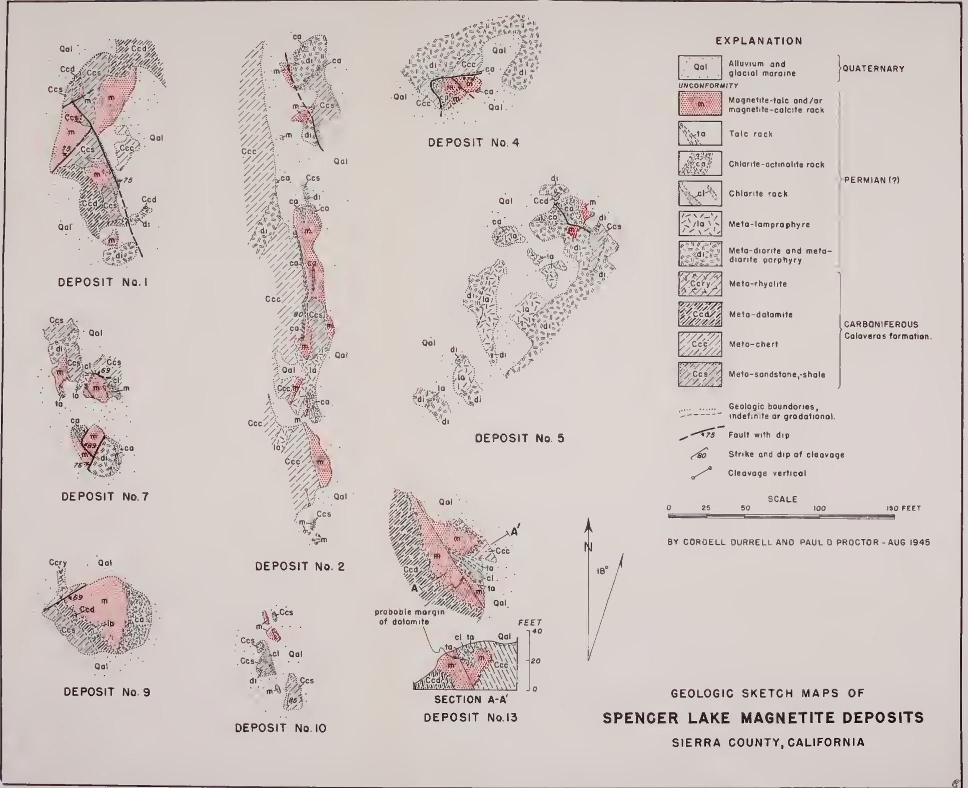

GEOLOGIC SKETCH MAPS OF

SPENCER LAKE MAGNETITE DEPOSITS

SIERRA COUNTY, CALIFORNIA

magnetite, accomplished by crushing. The extension of the rock in the direction of cleavage accounts for the separation of the crushed parts of larger units. The direction of the cleavage and extension of the magnetite is independent of the direction of the bands, and therefore the banding cannot have originated by dynamothermal metamorphism; it is clearly earlier. Very likely there has been some recrystallization of both talc and magnetite, though it is not clear to what extent this has occurred.

Deposit 3 of the Lake Hawley group of deposits is similar to Deposits 1 and 2, and has afforded no further information on the origin and structure of the deposits.

The Spencer Lakes Group of Magnetite Deposits

Eight of the 13 deposits of the Spencer Lakes group of deposits are shown in detail on the accompanying map, plate XXIII. Their relative positions are shown on plate XX.

Deposit 1, the most southerly of the group, consists of five outcrops of magnetite rock, some of which contain talc, and some of which contain calcite. The whole area is only 120 by 50 feet. The relationships to the surrounding rocks are not clear. A part of the magnetite has evidently replaced sandstones and a part has replaced dolomite. The magnetite rock is bounded both by gradations into meta-sandstones and by fractures. The extension of magnetite along the southeast-trending fracture indicates that the fracture exerted some influence on the localization of the magnetite. The magnetite-talc is schistose.

Deposit 2 consists of a chain of outcrops of magnetite-talc rock 320 feet long, with a maximum width of magnetite-talc rock of 12 feet. The magnetite-talc rock is in most places bordered by a zone of chlorite-actinolite rock that is an alteration product of the wallrocks and is analogous to the chlorite rock of the Lake Hawley deposits. Apparently the rock replaced was the metamorphosed sediments of the Calaveras formation, though lamprophyre may have been involved. The magnetite is evidently localized by a contact between meta-chert and the originally fine-grained clastic sediments. The magnetite-talc rock is schistose and is faintly banded.

Deposit 3 is a very small outcrop of magnetite rock surrounded by moraine; it was not mapped.

Deposit 4 consists of a nonschistose mass of magnetite and talc, that is 23 feet long and 12 feet wide. The magnetite-talc rock is separated from chert by a fracture, and elsewhere grades abruptly into chlorite-actinolite rock which is probably an alteration product of a lamprophyre dike. The deposit is within the meta-diorite intrusion.

Deposit 5 consists of two small areas of magnetite-talc rock that have clearly replaced lamprophyre which is intrusive into the large diorite body. The map of this deposit was extended to the south in order to show the relationships of the meta-lamprophyre and meta-diorite. The sample of meta-lamprophyre described above as being the least altered that could be obtained came from this dike at the south edge of the map. The meta-lamprophyre grades rapidly northward into nonschistose chlorite rock in which the original texture is clearly evident under the microscope. Near the center of the area mapped the lamprophyre is altered to chlorite rock which contains scattered crystals of magnetite; in it the original lamprophyric texture is still evident.

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Deposit 5 consists of two small areas of magnetite-talc rock that have clearly replaced lamprophyre which is intrusive into the large diorite body. The map of this deposit was extended to the south in order to show the relationships of the meta-lamprophyre and meta-diorite. The sample of meta-lamprophyre described above as being the least altered that could be obtained came from this dike at the south edge of the map. The meta-lamprophyre grades rapidly northward into nonschistose chlorite rock in which the original texture is clearly evident under the microscope. Near the center of the area mapped the lamprophyre is altered to chlorite rock which contains scattered crystals of magnetite; in it the original lamprophyric texture is still evident.

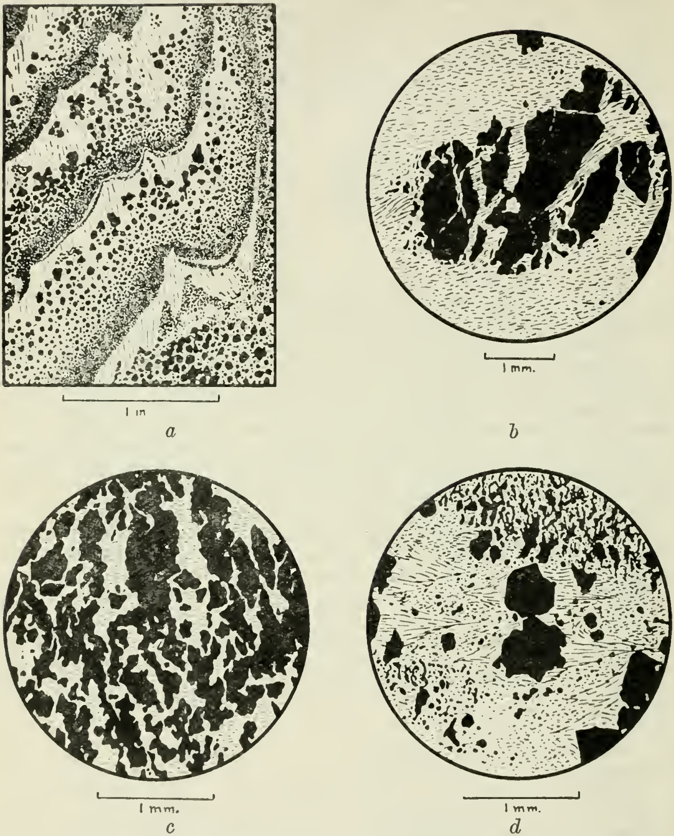

FIGURE 57. *a,* Details of the banded magnetite-talc rock from Deposit 1, Lake Hawley group of deposits. Drawn from a hand specimen. *b,* Crushed magnetite grain in talc. Fragments are elongated transverse to cleavage with coarse talc in pressure shadows between fragments. From Deposit 2, Lake Hawley group of deposits. *c,* Magnetite grains elongated across the cleavage in talc. From Deposit 2 of the Lake Hawley group of deposits. *d,* Pressure shadows of coarse talc about magnetite grains. In banded magnetite-talc rock from Deposit 2 of the Lake Hawley group of deposits.

In the three small outcrops just southwest of the magnetite, the chlorite rock contains abundant magnetite, and the original texture of the lamprophyre cannot be seen. Here also are bands of chlorite-actinolite rock, and actinolite rock, particularly well developed at the contact between the meta-lamprophyre and the meta-diorite. Adjacent to the magnetite-talc rock, the altered lamprophyre is mapped as chlorite-actinolite rock though it is clearly part of the same dike. The magnetite rock occurs in the altered lamprophyre. The apparent occurrence of the south body of magnetite within the meta-diorite is due to a topographic effect not apparent on the map; the magnetite rests against meta-diorite on a steep contact that dips to the north. The diorite was not affected by the processes that resulted in the alteration of the lamprophyre. None of the rocks described above is schistose.

At this locality it is clear that the meta-lamprophyre was hydrothermally altered, that the alteration increases in intensity toward the magnetite rock, and that the alteration products are chlorite, actinolite, and probably the talc associated with the magnetite. The spacial relationships indicate that the magnetite mineralization was a part of this epoch of alteration, and the deposit is therefore to be considered hydrothermal. The mineralization is younger than the lamprophyre which in turn is younger than the diorite.

Deposit 6 was not mapped. It consists of an outcrop of magnetite and calcite, 5 by 11 feet, surrounded by morainal deposits.

Deposit 7 consists of four outcrops of magnetite in an area 80 by 35 feet. The magnetite is bounded in part by fractures which probably controlled its localization, and by sharp gradations into chlorite rock which in turn grades into meta-sediments. It is noticeable that diorite dikes were not affected by the mineralization.

Deposit 8 is a very small deposit in meta-sediments. It was not mapped because of its small size.

Deposit 9 consists of a knob-shaped mass of nonschistose magnetite rock about 45 feet in diameter surrounded by alluvium and mill tailings from the Four Hills gold mine. The eastern part of the knob consists of magnetite and talc in contact with chlorite-actinolite rock. The western part consists of magnetite and calcite, and is in contact with dolomite. It is in contact on the north, across a small fault, with meta-rhyolite. Evidently the magnetite was localized by the intersection of the fault and the contact between dolomite and clastic sediments, lamprophyre, or intermediate tuffs. That part which replaced the dolomite contains calcite, and that which replaced the other rocks contains talc. The same relationship holds at Deposit 13.

A noteworthy feature of the magnetite rock of this deposit is the occurrence of clinochlore and apatite in good crystals. The solution of calcite by weathering has left abundant cavities in the outer surface of the magnetite rock. The magnetite in the cavities consists of octahedral crystals modified by the dodecahedron, from 0.5 to 2 millimeters in diameter. The walls of many of the cavities are partly to completely coated with small but perfect crystals of clinochlore which thus form an incomplete film between magnetite and calcite. Here and there over the outcrop there are cavities which contain grayish-white crystals of apatite, ranging in size up to 2 by 10 millimeters. The apatite crystals are not embedded in the magnetite, but are molded against it, and were evidently formed only in the calcite or chlorite.

Deposit 10 consists of three small outcrops of magnetite-talc rock closely associated with chlorite rock derived from the fine shaly sandstones. The largest of the outcrops is only 2½ by 9 feet.

Deposit 11, which was not mapped because of brush, is similar to Deposit 10 and about the same size.

Deposit 12, also not mapped, consists of three blocks of magnetite rock from 2 to 5 feet in diameter resting on moraine, a large number of smaller fragments scattered over an area roughly 150 by 50 feet, and a few small veinlets of magnetite in meta-dolomite associated with chlorite rock and veins of clinochlore. Some of the magnetite of the blocks consists of lodestone in crystals as much as 80 millimeters in diameter. Octahedrons of magnetite as much as 15 millimeters in diameter are present in small cavities. Veins of clinochlore and veins of finely columnar dolomite are present in the coarse magnetite. Probably here, as at Deposits 9 and 13, mineralizing fluids rose along a contact between dolomite and clastic sediments, and magnetite was deposited on both sides of the contact.

Deposit 13 consists of a single lenticular outcrop of magnetite rock, 90 feet long and 40 feet in maximum width. The eastern part of the outcrop consists of schistose and banded magnetite-talc rock in contact with chlorite rock, talc rock, and meta-chert; the western part consists of massive magnetite and calcite in contact with meta-dolomite. A line is shown on the accompanying map that marks the limit of magnetite and calcite. This line approximates the pre-existing boundary between dolomite and clastic sediments. It will be noted that it is a straight boundary, and that chlorite rock and talc rock as well as magnetite-talc rock occur only on the eastern side. The accompanying cross-section (A—A′, pl. XXIII) is an attempt to interpret the nature of the deposit in depth. It is apparent that the mineralizing solutions rose along a contact between dolomite and other sediments, and that magnetite was deposited in rocks on both sides. The resulting character of the magnetite rock was controlled by the nature of the replaced rocks. Later dynamothermal metamorphism has produced a schistosity in the magnetite-talc rock, but not in the magnetite-calcite rock.

Conclusions Regarding the Origin and History of the Magnetite Deposits

It has been shown that all of the rocks belonging to the "bedrock series", except the quartz monzonite and the auriferous quartz veins, have been dynamothermally metamorphosed. The metamorphism gave rise to a cleavage that is present in nearly all rocks except the large meta-diorite intrusion east of Spencer Lakes. This body was evidently sufficiently massive to resist the development of cleavage, and also to protect a narrow marginal zone of the sediments of the Calaveras formation that are also nonschistose.

The magnetite rocks also were dynamothermally metamorphosed as is shown by the presence in them of cleavage, pressure shadows, and granulation of the magnetite. Only those magnetite deposits within the diorite near Spencer Lake or in the nonschistose marginal zone of Calaveras rocks are nonschistose; deposits both north and south of the diorite are schistose. Thus the magnetite rocks are older than the dynamothermal metamorphism.

The magnetite rock is younger than faults and fractures in the Calaveras formation that evidently controlled its position; it is possible

that these structures were formed by the disturbance that produced the unconformity at the top of the Calaveras formation. The magnetite rock has replaced lamprophyre that is younger than the diorite which in turn is younger than the Calaveras formation. The magnetite cannot therefore have been syngenetic with respect to the enclosing sediments. The magnetite-talc rocks are accompanied by talc rock, chlorite rock, chlorite-actinolite rock, actinolite rock, and by veins of chlorite, dolomite, and serpentine, all of which are of hydrothermal origin and are derived by alteration and replacement of the several rock types of the Calaveras formation and of lamprophyre. Hydrothermal origin of the magnetite is indicated by its association with the above-mentioned rocks, and the fact that it is younger than the enclosing Calaveras formation.

That the magnetite rocks are replacements of several types of rocks seems sufficiently clear from the contact relationships described in the foregoing sections.

The magnetite mineralization is probably genetically connected with the premetamorphic basic igneous rocks. The magnetite deposits are younger than lamprophyres that cut the diorite, but if the lamprophyres are genetically associated with the diorite, the magnetite is probably very little younger than the diorite. The diorite in turn is probably an intrusive phase of the more widespread igneous activity that produced the post-rhyolite series of basic flows and tuffs. This series is probably Permian in age, and this age is very likely that of the magnetite mineralization.

The magnetite deposits of the Spencer Lakes group are closely associated spacially with the meta-diorite intrusion, and are therefore thought to be related to that body. No such intrusion is known in the vicinity of the Lake Hawley deposits, but it has been suggested, in view of the local abundance of meta-diorite porphyry dikes in the vicinity of Lake Hawley, that a similar body may be present there though not yet exposed by erosion.

The subsequent metamorphism accompanying the Nevadan orogeny superimposed a schistosity on the magnetite deposits, and possibly effected important dislocations in them and in accompanying rocks.

The origin of the banding in the magnetite-talc rock is still unsolved. It may be premetamorphic, but it does not reflect any known original structure in the replaced rocks. It probably originated during the process of replacement.

Whether the talc that accompanies the magnetite was original, or whether some other mineral was present from which the talc was derived by dynamothermal metamorphism, is still unknown. The same is true of the chlorite. It has been assumed above that these minerals were in existence as such before the metamorphism. That this is probably so is indicated by the fact that no relicts of pre-existing minerals have been found either in the field, in hand specimens, or in thin-sections, and by the fact that at Deposit 5 of the Spencer Lakes group chlorite rock and chlorite-actinolite rock were derived from lamprophyre in such a way as to preserve perfectly the original texture of the igneous rock. It is at least probable that dynamothermal metamorphism affected only the texture and structure of the hydrothermal rocks and not their mineralogy. This would be expected, for the minerals in question are such as would normally be present in rocks of appropriate composition at the

prevailing low grade of dynamothermal metamorphism that has affected the region.

ECONOMIC GEOLOGY

It is apparent from the descriptions above that most of the magnetite bodies are of insignificant size. Only Deposit 1 of the Lake Hawley group is sufficiently large to merit consideration as a potentially workable ore body. For that reason, and because there is little difference in the relative amounts of magnetite and gangue in the several ore bodies, calculations of grade are based on samples from this deposit, and from the nearby Deposit 2 which is identical though smaller.

Character of Ore

It is evident from field and microscopic examination of the magnetite-bearing rocks that there are two types present; one consists of magnetite and calcite, and the other of magnetite and talc. There are small amounts of magnetite with chlorite, but only in the minor deposits of the Spencer Lakes group.

Apatite and chlorite are present in the magnetite-calcite ore of Deposit 9 of the Spencer Lakes group, and a small amount of a mineral that is possibly apatite, but which was not positively identified, is present in one sample from Deposit 1 of the Lake Hawley group. Chlorite is present in small amounts, probably not exceeding 2 percent, in many specimens of magnetite-talc rock from both groups of deposits. The small amounts of titanium and alumina in the analysis below are probably contained in chlorite. Pyrite is present here and there but probably never approaches 1 percent. It is clear from the microscopic examinations that the ores consist of either magnetite and talc, or magnetite and calcite, and that there are insufficient amounts of other minerals present to be deleterious.

No chemical analyses of ores have been made in connection with the present report, but some partial analyses are available. James P. Little and Olaf P. Jenkins of the California State Division of Mines collected samples from Deposit 1 of the Spencer Lakes group, from which the following data were obtained.[17]

Analyses of ore from Deposit 1, Lake Hawley group of deposits

Sample	I	II	III	Average I-III
	Percent	Percent	Percent	Percent
Total iron	38.97	39.58	37.77	38.77

Composite nonmetallic fraction of samples I to III

	Percent	
SiO_2	27.95	
Al_2O_3	0.89	
MgO	11.95	
CaO	0.31	
Ti	0.15	
P	0.15	
S	Tr.	
	41.40	
Difference	58.60	presumably magnetite

The average iron content of samples I to III—38.77—corresponds to 53.5 percent magnetite. The balance, presumably magnetite, of the composite analysis of the nonmetallic fraction of samples I to III, is 58.60 percent. The discrepancy is not large. The analysis serves to show an absence of deleterious amounts of titanium, phosphorus, and sulfur.

[17] Unpublished. Samples collected in 1944. Analyses by Abbot A. Hanks, Inc.

The following analysis, by Professor H. Schrother of Vienna, is quoted by Putnam [18] from the unpublished report of King and Hauge. The source of the sample is not given.

Analysis of ore from unspecified locality

	Percent
Protoxide of iron	26.40
Peroxide of iron	57.40
Silicic acid	15.87
Carbonate of lime and loss	0.33
	100.00

The total iron is 60.6 percent, and the ratio of FeO to Fe_2O_3 is very close to that for magnetite. It appears, however, that the sample consisted of magnetite and free silica, presumably quartz. No such material was found in the present examination, and therefore the sample cannot be considered representative.

Grade of Ore

Seven samples collected from Deposits 1 and 2 of Lake Hawley group were used to determine the amount of magnetite present. The specific gravities of pieces ranging in weight from 82.7 to 246 grams were determined. In each case the piece was considered large enough to eliminate any error due to banded heterogeneities. All were examined under the microscope and no important quantities of minerals other than talc and magnetite were present. One sample of magnetite-calcite rock with apatite and chlorite from Deposit 9 of the Spencer Lakes group was also measured. The weight percent of magnetite and iron in each sample was then calculated. Samples II, IV, and V which were judged in the field to be typical of the deposits fall well within the extreme of the seven samples of talc-magnetite rock. The results of the calculations are presented below.

Calculated compositions of ores from Lake Hawley and Spencer Lakes groups of deposits

Sample	Specific gravity	Magnetite (percent)	Iron (percent)
I	3.65	37.5	27.2
II	3.35	24.7	17.8
III	3.28	21.8	15.8
IV	3.64	36.7	26.6
V	3.50	30.9	22.4
VI	3.26	21.0	15.2
VII	3.36	25.2	18.3
VIII	4.53	60.0	43.5
Average I to VII	3.43	28.2	20.4

I. Dense black magnetite-talc rock from Deposit 2, Lake Hawley group. Contains less than 1 percent chlorite.
II. Coarse-grained magnetite in talc from Deposit 2, Lake Hawley group. Contains no other minerals. Considered to be representative.
III. Coarse-grained magnetite in talc from Deposit 2, Lake Hawley group. Contains no other minerals.
IV. Poorly banded magnetite-talc rock from Deposit 2, Lake Hawley group. Contains a little red-brown oxide, presumably from oxidation of pyrite. Considered to be representative.
V. Banded magnetite-talc rock from Deposit 1, Lake Hawley group. Contains a small amount of fine colorless needles that may be apatite. Considered to be representative.
VI. Banded magnetite-talc rock from Deposit 1 of Lake Hawley group. Contains no other minerals.
VII. Finely banded magnetite-talc rock from Deposit 1 of Lake Hawley group.
VIII. Dense magnetite-calcite rock from Deposit 9 of Spencer Lakes group. Contains apatite and chlorite.

The calculated values of the iron content obtained by the present writers are lower than those found by Little and Jenkins, as quoted above. Since there is no overlap between the two sets of data, and because the

[18] Putnam, Bayard T., Notes on the samples of iron ore collected west of the one hundredth meridian: 10th Census U. S., vol. 15, p. 494, 1886.

present writers carefully selected samples believed to be representative of the deposits as a whole, it is thought that those collected by Little and Jenkins were richer than the average. This opinion is supported by the fact that in their report they give the specific gravity of the magnetite-talc rock as 3.62 which corresponds to a magnetite content of 35.8 percent. This value, though higher than the average obtained by the present writers and higher than any sample considered to be representative, does fall within the range of values obtained.

It is probable that the average amount of magnetite and of iron will not exceed 30 percent and 21 percent respectively in the three deposits of the Lake Hawley group, and in those deposits of the Spencer Lakes group that consist of magnetite and talc. In the part of the Spencer Lakes group that is composed of magnetite and calcite the average may be higher, but the material is extremely variable.

Probable Continuation of the Ore Bodies in Depth

Since the deposits are of hydrothermal origin there is no reason to assume that they were once parts of large bodies or that they have any great continuity in depth. Though dislocations may have occurred, the deposits probably originated separately. The original form of the ore bodies has no doubt been changed by the folding and dynamothermal metamorphism, and since they now appear roughly lenticular in plan, it seems reasonable to assume that they have about the same shape in cross-section. This view is supported by the fact that the outcrops of the small Deposits 4, 5, and 10 of the Spencer Lakes group, and the eastern part of Deposit 1 of the Lake Hawley group at the north end, can be seen to narrow downward. Furthermore, it has been shown that Deposit 1 of the Lake Hawley group, which looks superficially as though it might be a pipe-like body with a considerable continuity in depth, consists of at least two bodies separated by a septum of barren rock. Most probably it consists of three such separate bodies, as shown in Section A—A′ of plate XXI.

The ore bodies probably have a continuity in depth not greater than the largest dimension in plan; but it must be recognized of course that the present downward extension may be larger than that value in some deposits, and less in others.

Magnetic Survey of the Lake Hawley Group of Deposits

The magnetic survey of the Lake Hawley group of magnetite deposits was made as an attempt to discover whether outcrops separated from one another by morainal material were connected below, to locate any unexposed magnetite bodies, and to determine, if possible, the size, shape, and attitude of any concealed or partly concealed bodies.

The survey was made with an S. G. Pollard Co. "pipe finder" dip needle. The values of intensity shown on the accompanying map, plate XXII, are the scale unit readings of the dip of the magnetic needle, when held in a vertical plane defined by magnetic north at the point of observation. The scale units were considered positive when the north end of the needle was depressed, and negative when the south end was depressed. The dip needle was adjusted to read zero over the adjacent rock. The data for the map, plate XXII, were obtained from pace traverses between stadia survey points not more than 100 feet apart.

Readings were taken at intervals of 5 feet where the values changed rapidly, and elsewhere at intervals of 10 feet.

No important extensions of the central part of Deposit 1 are indicated by the survey, and the shapes of the lines of equal dip-needle inclination correlate well with the shape of the outcrops.

The relatively high values of intensity between the two small outcrops immediately east of the central part of Deposit 1 indicate a possible continuation of magnetite beneath the intervening morainal material.

The extreme northwestern and southeastern outcrops of Deposit 1 are evidently small isolated bodies.

Immediately south of the central area of Deposit 1 is a small area of low intensity which may be related to a small body concealed by moraine, or to a larger body at such depth as to have little effect upon the dip needle.

High values of magnetic intensity are present over Deposit 2, and the shapes of the lines of equal dip-needle inclination correlate well with the shape of the outcrop except on the south side where high values extend southeastward in a zone up to 70 feet wide for a distance of 300 feet. In this area the bedrock is largely concealed by moraine, and there are no outcrops of magnetite rock. From these facts it may be inferred that there is another body as large or larger than the exposed part of Deposit 2 concealed beneath the moraine. This inferred body may actually be connected at depth with Deposit 2.

Traverses were run between all exposed areas of magnetite rock and no other notable anomalies were found. It is believed, therefore, that either the intervening areas contain no magnetite rock, or any magnetite rock present is at such a depth as not to influence the dip needle used in the survey.

Estimated Quantities of Magnetite Available

The reserves of the Lake Hawley group of deposits have been calculated in three ways. First, the tonnage of magnetite is estimated as a total an an assumption of total depth as shown on sections A-A′ and B-B′ of plate XXI. Corresponding values were assumed for Deposit 2 for which no cross-section was constructed. Second, the tonnage is given for each 10 feet of depth for each area of outcrop. A third estimate is based on the magnetic map (pl. XXII), which indicates that the two small areas of magnetite southeast of Deposit 1 are parts of a larger body, and that Deposit 2 extends about 300 feet to the southeast. These values are based on a unit 10 feet of depth for areas analogous to the main part of Deposit 1. No assumptions as to total depth of ore can be made for the unexposed areas, but it seems probable that it will not exceed 100 feet. The magnetite content for all deposits is taken to be 30 percent.

Tons of magnetite available, Lake Hawley group of deposits

	Deposits			Total
	1	2	3	
Estimated total tons of magnetite for areas of outcrop	31,000	3,500	3,200	37,700
Estimated tons of magnetite per 10 feet of depth for areas of outcrop	7,200	900	800	8,900
Estimated additional tons of magnetite per 10 feet of depth for concealed areas based on magnetic map	2,700	5,100	not included	7,800
Total tons of magnetite per 10 feet of depth for all possible areas	9,900	6,000	800	16,700

Figures from the first two methods of calculation given in the first and second lines of the table above represent reasonably certain estimates for the tonnage of magnetite in sight. The total of the first line is based on assumed values for the continuation in depth that are different for each area of outcrop. Dividing the total of the first line by that of the second line gives the average assumed depth of continuation for all bodies, which is 42 feet. The third line gives the additional amount of magnetite inferred per 10 feet of depth. The grand total per 10 feet of depth is 16,700 tons of magnetite. If the average continuation in depth for all exposed and concealed areas should be as much as 100 feet, which is very doubtful, the amount of magnetite would probably not exceed 167,000 tons. This last figure may be considered the most optimistic view that can be taken. It must be concluded that the sum total of all deposits of the Lake Hawley group constitutes at most only a tiny reserve of iron ore.

For the Spencer Lakes deposits it has been assumed that each area of outcrop is a separate ore body, that the continuation in depth is equal to the maximum dimension in plan, and that the subsurface form of the body is roughly a triangular prism. The content of magnetite is taken to be 30 percent in those bodies composed of talc and magnetite, and 60 percent for those parts of Deposit 9 and Deposit 13 composed of calcite and magnetite. This is probably the most optimistic view that can be taken, yet the largest deposit (number 13) contains only 3,117 tons of magnetite, and the total for all deposits measured is only 8,200 tons of magnetite. The deposits not included in the calculation contain a negligible amount of magnetite.

Tons of magnetite available, Spencer Lakes group of deposits

Deposit	Total tons of magnetite
1	1,125
2	1,644
3	negligible
4	94
5	23
6	10
7	253
8	negligible
9	1,910
10	15
11 (estimated to be same as 10)	15
12	negligible
13	3,117
Total	8,206

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
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PART M

Iron Deposits of the Kingston Range, San Bernardino County, California

By D. F. Hewett
Geological Survey, U. S. Department of the Interior

Issued by the
STATE DIVISION OF MINES

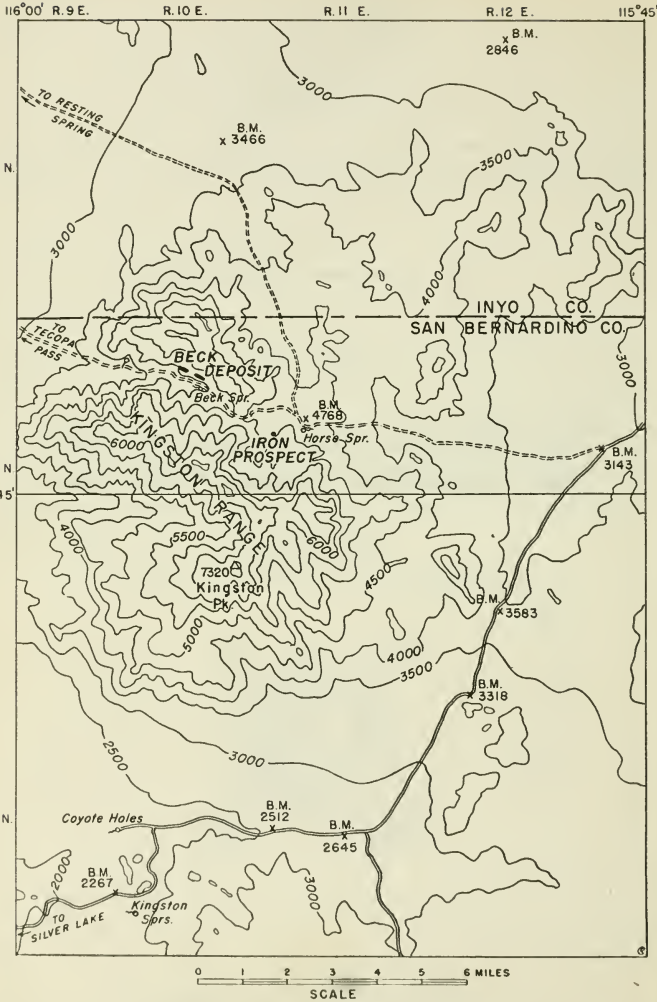

FIGURE 58. Map showing location of the iron-ore deposit of the Kingston Range, San Bernardino County, California

IRON DEPOSITS OF THE KINGSTON RANGE SAN BERNARDINO COUNTY, CALIFORNIA*

By D. F. Hewett**

OUTLINE OF REPORT

ABSTRACT

Iron deposits are known at two localities in the Kingston Range, which is a nearly circular mountain mass lying in the northeastern corner of San Bernardino County, California. The principal deposit, known as the "Iron Gossam" or Beck deposit, is in the northern part of the range along the north side of a deep valley that drains westward; the second and much smaller deposit lies about 3 miles east of the Beck deposit, near the head of a valley that drains northward. Both deposits are accessible by roads from Tecopa, about 20 miles west, and from Jean, Nevada, a station on the Union Pacific Railroad about 40 miles to the east. The deposits lie in a rugged unsettled region and will present numerous problems of exploitation. There is a scarcity of water; two springs near the Beck deposit yield a total of about 6 gallons of water a minute and another, 3 miles distant, and near the smaller deposit, yields about 5 gallons a minute.

Both iron deposits are in limestone beds of the Crystal Spring formation, the lowest of three sedimentary formations that make up the Pahrump series of pre-Cambrian age. The rocks of the Pahrump series are intruded by a great body of late Cretaceous or early Tertiary monzonite porphyry (here named the Kingston Range monzonite porphyry) that forms the central core of the Kingston Range, and the iron deposits appear to be related to this body of intrusive rock. Sills of amphibole rock, which was at one time syenite, have intruded the Crystal Spring formation but they antedate the iron deposits; small dikes of andesite are later than the ore.

The Beck ore bodies are rather simple lenses of magnetite, martite (hematite derived from magnetite), and hematite; a small amount of pyrite is present. The nearby limestone is sporadically altered to iron-carbonate rock, serpentine, wollastonite, tremolite, and garnet. The lenses of iron oxides are nearly vertical and conformable with the bedding of the limestone. The local geologic features indicate, and some of the drill holes confirm, the fact that the rocks containing the iron deposits are part of an enormous fault block that has been thrust eastward on old gneissic rock for many miles. It is concluded, therefore, that the iron deposits do not extend into the older rocks, or below a datum of about 3,750 feet.

As the result of a program of drilling in 1924, the extent of the outcropping bodies of iron ore is rather accurately known. All of the ore lies above the 3,750-foot level, and can therefore be mined from open-cuts and tunnels.

*Published by permission of the Director, U. S. Geological Survey. Manuscript submitted for publication May 29, 1947.

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INTRODUCTION

In September 1924, the writer began the project of geologic study and mapping of the Ivanpah quadrangle, in Inyo and San Bernardino Counties, California, and Clark County, Nevada. Fortunately, work in the Kingston Range which lies in the northwest corner of the quadrangle coincided with a program of drilling of the iron-ore bodies known as the Beck deposit, and it was possible to examine the cores derived from the drill holes and to interpret them in the light of general knowledge of the geology of the region. The drilling, done in the fall and early winter of 1924, was under the supervision of H. R. Plate of San Francisco, now deceased, who was directing the work for the owner, the Pacific Coast Steel Company. Through their courtesy, permission was granted to use the results of the drilling in preparing an account of the geology of this area. Work in the Ivanpah quadrangle was completed in 1929 but other duties have delayed the preparation of the full report. The present paper gives a brief account of the geology of the iron deposits.

Location and Water Supply

The Kingston Range is a rugged, nearly circular mountainous area, about 10 miles in diameter, that lies near the northeast corner of San Bernardino County, California (fig. 58). Tecopa, California, a station on the abandoned Tonopah and Tidewater Railroad, lies about 20 miles to the northwest. A poor desert road extends from the iron deposits to Tecopa, which will be the probable point of shipment of ore, if and when the iron deposits are exploited. Jean, Nevada, a station on the Union Pacific Railroad that extends to San Bernardino and Los Angeles, lies about 40 miles east of Kingston Range. A fair desert road extends from the iron deposits through Kingston, California, and Sandy and Goodsprings, Nevada, to Jean, Nevada.

Except on the northeast, Kingston Range rises abruptly from desert plains having an elevation of about 3,000 feet, and culminates in Kingston Peak which has an elevation of 7,320 feet. In a broad way, deep rugged valleys drain radially outward from the high point of the range. In the northern part of the range, a deep valley drains west to Amargosa Valley; the Beck iron-ore bodies lie along the north slopes of this valley about a mile west of the low divide that marks the head of the valley.

Water is scarce in the Kingston Range; only three springs are known in an area of about 80 square miles. Beck Spring rises in the talus along the south slope of the valley a few hundred feet from one of the iron-ore bodies; in 1924 the discharge was about 4 gallons a minute. Crystal Spring rises in the talus along the north side of the valley, about 2 miles west of Beck Spring; in 1924 the discharge was 2 gallons a minute. Horse Spring lies about 3 miles east of Beck Spring, at the head of a valley that drains eastward to Mesquite Valley; in 1924 it discharged about 5 gallons of water a minute. With appropriate improvements, the discharge of these springs probably could be doubled.

GENERAL GEOLOGY

In the central part of Kingston Range, four major groups of rocks are exposed: (1) granite gneiss of pre-Cambrian age, the oldest rock in the area; (2) a variable group of sedimentary rocks that has been

named the Pahrump series, pre-Cambrian in age; (3) a second and more uniform group of sedimentary rocks, comprising the Noonday dolomite of Cambrian age; and (4) an intrusive igneous rock, the Kingston Range monzonite porphyry, assigned to the period of Laramide orogeny—late Cretaceous or early Tertiary. Still younger rocks—sediments and lava flows probably middle Tertiary in age—are found in the hills that lie south of Kingston Range and serve in interpretation of the nature and age of some structural features that are important in considering the iron-ore deposits.

Gneiss (Pre-Cambrian)

At various places in the bottom of the valley, for about 7,000 feet westward from Beck Spring, there is exposed a greenish-gray granite gneiss that characteristically is made up of coarse white orthoclase, quartz, muscovite, and chlorite. The rock is quite different from, and should not be confused with, the Kingston Range monzonite porphyry that crops out along the south border of the gneiss. Similar gneiss was encountered at a depth of 679 feet in drill hole no. 2, which penetrated 111 feet into it, and at a depth of 415 feet in drill hole no. 8, which penetrated 187 feet into it.

The recorded distribution of granite gneiss would be difficult to interpret if there were not available much information concerning the structural relations of the gneiss to other rocks in the region that lies as much as 20 miles east and south of Kingston Range. In view of these relations, it is quite clear that the granite gneiss is the basement across which in late Tertiary time there was thrust an enormous plate of rocks of complex composition.

Pahrump Series (Pre-Cambrian)

The iron deposits of this area occur in rocks that lie near the base of the section of the Pahrump series at least 5,300 feet thick, that is exposed on the north slope of the valley which drains westward from Beck Spring. For purposes of mapping, the Pahrump series is separated into three mutually conformable units: (1) Crystal Spring formation at the base, (2) Beck Spring dolomite in the middle, and (3) Kingston Peak formation at the top.[1] Near the Beck iron deposit the members of the Pahrump series and the overlying Noonday dolomite strike generally northwest and dip northeast at angles that range from nearly vertical at the base of the section to 75° NE. in the Noonday dolomite.

Crystal Spring Formation

At the base, where it rests unconformably on granite gneiss, the Crystal Spring formation begins with a quartz conglomerate and conglomeratic quartzite as much as 1,000 feet thick. However, the base is not exposed near the Beck deposit. Beginning at an unmeasured but probably small interval above the quartzite, the following section of strata that dip steeply northeastward was measured on the ridge that rises northward from the iron deposit:

[1] Hewett, D. F., New formation names to be used in the Kingston Range, Ivanpah quadrangle, California: Washington Acad. Sci. Jour., vol. 30, pp. 239-240, 1940.

Top of section (base of Beck Spring dolomite)	Feet
Shale, sandy, olive	200
Shale, silicified, brown; resembles hornstone	60
Dolomite, massive, buff	40
Dolomite, shaly, buff, with sparse blue chert	200
Shale, sandy, reddish purple; contains several beds of buff dolomite, also sporadic zones of quartzite pebbles up to half an inch in diameter	250
Shale, sandy, red	30
Dolomite, gray, not persistent	30
Shale, slaty, green and purple	200
Dolomite, gray	20
Shale, green and brown	20
Shale, green and black; locally slaty; quartzite layers near top	250
Shale, green	10
Limestone, white, crystalline; much fractured and cut by veins of ferruginous chert which merge with lenses of magnetite and hematite; contains the two explored bodies of iron ore (Beck deposit); at top, there are lenses of green amphibolite rock, which intrude the limestone	100
Shale, dense, green	10
Amphibole rock, dense, dark green; probably a sill 300 feet or more thick; contains a part of the western iron-ore body of the Beck deposit	300+
Total	1720+

The green amphibole rock crops out persistently under the limestone and is cut by most of the drill holes. In some holes (as in no. 4) it forms a single layer nearly 500 feet thick below the limestone bed, but in other holes it forms two, three, or even four layers separated by layers of limestone or iron ore. The evidence favors the idea that the rock was intruded as sills that closely followed the bedding of the sediments, probably in pre-Cambrian time. Most of the material is coarse grained and mottled white and dark green. A specimen from the tunnel on Iron Gossam No. 5 claim shows, under the microscope, a little orthoclase and plagioclase in a groundmass of actinolite, epidote, and chlorite. It is clearly an altered rock, probably syenite, in which hornblende or augite has been replaced by actinolite. In the drill cores most of the rock appears to be relatively unaltered, but it has not been studied closely. As it contains lenses of magnetite and hematite, it antedated the formation of the iron ores.

The drill cores from several holes show bodies of two varieties of fine-grained igneous rock, one a reddish-brown rock with conspicuous blades of feldspar (drill hole no. 8, 409-415 feet), and the other a dense, greenish rock (drill hole no. 2, 186-202 feet). They have not been studied closely, but are considered varieties of andesite. They form dikes that crop out on the surface. Although believed to be much later than the amphibole rock and probably later than the ore, they are mentioned here because of their proximity to the amphibole rock in the ore-bearing zone.

Beck Spring Dolomite

The Beck Spring dolomite forms a conspicuous unit about 1,100 feet thick which crops out in a belt about 6 miles long on the north and east sides of Kingston Range. It consists largely of beds of bluish-gray dolomite 2 to 4 feet thick, separated by thinner layers of shaly material. No identifiable fossils have been found in it but some beds contain algae-like concretions and oolites.

Kingston Peak Formation

North of the iron deposits the thickness of the Kingston Peak formation is about 2,000 feet, but it increases to the east. The unit is roughly separable into three parts of about equal thickness. The lowest part is largely thin-bedded dark-gray limestone and sandstone; in the sandstone there are imbedded sporadic subangular chert and dolomite pebbles, the number and size of which increase upward. The middle part consists largely of subangular cobbles of quartzite and limestone from 4 to 12 inches in diameter in a sandy matrix. The highest part resembles the middle part but limestone pebbles predominate and their number and size steadily decline upward.

Some features of this unit suggest a tillite of glacial origin but no striated pebbles have been found. On the other hand, the formation shows many features of the modern alluvial fans of this desert region.

Noonday Dolomite (Cambrian)

The Noonday dolomite, identified and named by Hazzard,[2] in the region of the Noonday mine which lies in the Nopah Range about 12 miles west of the iron deposits, is about 2,000 feet thick near the iron deposits but the thickness decreases steadily eastward; the dolomite is not known east of Mesquite Valley. In the Kingston Range it is massive, homogeneous, cream-colored dolomite with meager sandy and clay layers and traces of bedding. On the northwest slopes of Kingston Range, it is nearly conformable with the underlying Pahrump series, but on the northeast and east slopes, it is highly unconformable. At many places in the Kingston Range small lead deposits have been explored in the Noonday dolomite.

In the hills that lie north and northeast of Kingston Range, the Noonday dolomite is overlain successively by the Prospect Mountain quartzite and Pioche shale of Cambrian age and the Goodsprings dolomite of Upper Cambrian to Devonian (?) age.

Laramide Orogeny

At a period identified as "Laramide"—roughly late Cretaceous or early Tertiary—the pre-Cambrian, Paleozoic, and Mesozoic rocks of southeastern California and southern Nevada were deformed by folding and thrust-faulting and were intruded by large bodies of quartz monzonite. The lower Paleozoic rocks on the north and east slopes of Kingston Range show numerous complicated folds and thrust faults, but within the Kingston Range the pre-Cambrian Pahrump series forms a large dome in the center of which is a core of igneous rock, the Kingston Range monzonite porphyry. Where the sedimentary rocks are in contact with this porphyry, they show the varieties of alteration that are common near such intrusive rocks. A small body of magnetite in the sedimentary rocks near the monzonite contact has been explored near Horse Spring. The evidence of the region indicates that the iron deposit near Beck Spring was formed late in the epoch of Laramide orogeny and is related to the monzonite porphyry.

Kingston Range Monzonite Porphyry (Late Cretaceous or Early Tertiary)

A mass of monzonite porphyry about 7 miles in diameter forms the central core of the Kingston Range. It is here named the Kingston

[2] Hazzard, J. C., Paleozoic section in the Nopah and Resting Springs Mountains, Inyo County, California: California Div. Mines Rept. 33, pp. 273-339, 1937.

Range monzonite porphyry. Except that the texture is slightly finer near the contact with the sedimentary rocks that surround it on the north and east sides, the composition and texture of the monzonite porphyry are extremely uniform throughout this mass. Most outcrops show a thin film of brown desert varnish but fresh fractures are very light brownish to flesh color. Like most crystalline rocks of uniform composition and texture in desert regions, this porphyry weathers to smooth, rounded surfaces that are rugged in major aspect. The rock shows terminated crystals of white orthoclase, 3 to 8 millimeters long near the borders of the mass but 25 to 30 millimeters long in the central core, in a fine-grained matrix in which only biotite is conspicuous. In thin-section, the matrix is identified as minute grains of quartz and oligoclase (Ab_{80} An_{20}) with minor accessory titanite, magnetite, and zircon; hornblende is absent.

In mineralogy and chemical composition this rock closely resembles the quartz monzonite that underlies several hundred square miles of the central and southeastern part of the Ivanpah quadrangle. In texture, however, the Kingston Range body is porphyritic, in contrast to the coarsely crystalline character of the larger body of quarz monzonite to the southeast.

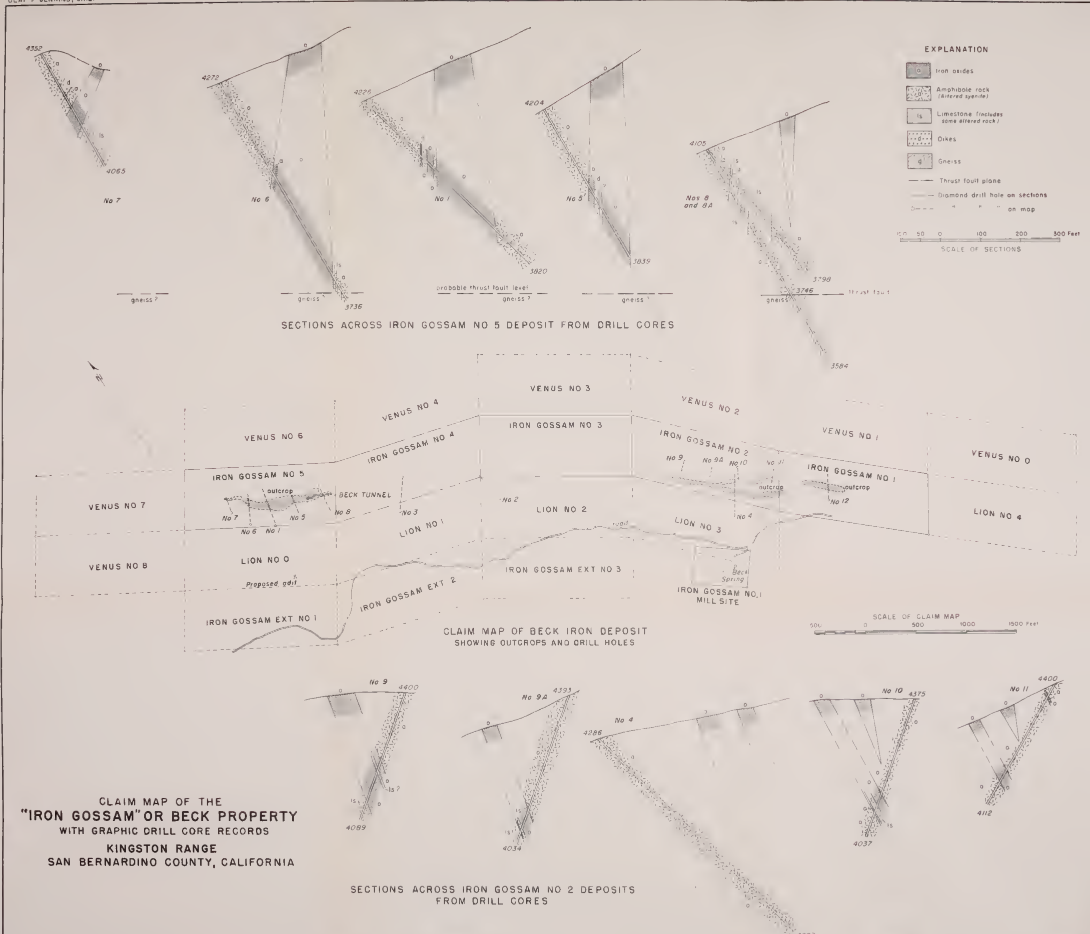
Middle Tertiary Rocks

Rocks of assured middle Tertiary age are not known in the Kingston Range or nearby hills, but are widely exposed in an area about 12 miles square (Shadow Mountains) that lies south of Kingston Wash, the principal drainage of a large area south of Kingston Range. The rocks are largely sediments—sand, gravel, clay, bentonite, volcanic ash —all relatively unconsolidated. Locally, in the northern part of the area, lava flows occur in the section. No fossils have been found in these rocks, but vertebrate fossils of lower Pliocene age have been collected from sediments of similar character in the Avawatz Mountains about 25 miles west of this area.[3] In the Shadow Mountains area, these Tertiary sediments rest upon the quartz monzonite which was reduced to a surface of low relief before the basal beds were deposited. The sediments dip eastward at low angles, mainly 10° to 30°, but are not folded.

Late Tertiary Orogeny

Within a large area in the northwest quarter of the Ivanpah quadrangle, including the Kingston Range and nearby hills to the northeast and east and the Shadow Mountains and hills as far south as Riggs Wash, large blocks of rocks that range in age from pre-Cambrian gneiss and sedimentary rocks to lower Paleozoic strata as young as the Goodsprings dolomite, rest in diverse attitudes upon middle Tertiary (lower Pliocene?) strata or pre-Cambrian gneiss. This area is about 20 miles wide in an east-west direction and 30 miles long in a north-south direction. In places, blocks as much as 3 miles long of granite gneiss with vertical foliation, rest upon relatively unconsolidated gravel, sand, clay, and volcanic ash. Elsewhere, blocks a mile or more long of lower Paleozoic sediments (particularly Goodsprings dolomite), that dip as much as 45°, rest upon almost horizontal surfaces of erosion cut across pre-Cambrian gneiss, and also across gravel, sand, and clay of undoubted lower Pliocene age.

[3] Henshaw, Paul C., A Tertiary mammalian fauna from the Avawatz Mountains, San Bernardino County, Calif.: Carnegie Inst. Washington, Pub. 514, pp. 1-30, 1939.



CLAIM MAP OF THE
"IRON GOSSAM" OR BECK PROPERTY
WITH GRAPHIC DRILL CORE RECORDS
KINGSTON RANGE
SAN BERNARDINO COUNTY, CALIFORNIA

These observations indicate that a large plate of rocks of diverse composition, at least 20 by 30 miles in area, was thrust eastward over an extensive flat surface of erosion that was cut after lower Pliocene time. The isolated blocks briefly described above are the remnants of this plate that have survived erosion since late Tertiary time.

As noted previously, the floor of the valley near the Beck iron deposit shows an area of about 1,500 by 7,000 feet of granite gneiss. Two drill holes (nos. 2 and 8), after passing through nearly vertical pre-Cambrian sedimentary rocks and sills, entered granite gneiss and continued in it for 100 feet or more. The granite gneiss was encountered at 3,755 feet above sea level in no. 2 hole and at 3,746 feet in no. 8 hole.

Similar conditions are found in Copperfield Flat about 5 miles northeast of the area described above. Chloritized granite gneiss crops out in a flat area about 2,000 by 8,000 feet and the surrounding hills include outcrops of the Noonday dolomite and Prospect Mountain quartzite in which the strata dip as steeply as 45° toward the granite gneiss surface on which they rest. From the topographic map it appears that the elevation of this gneiss surface ranges from about 3,700 to about 3,800 feet—or very near to that—near Beck Spring in Kingston Range.

From the foregoing description, which briefly summarizes a large amount of data from this region, the conclusion is reached that the entire Kingston Range, roughly 10 miles in diameter, is a part of the great plate of rocks which has been thrust eastward many miles, at least 20 and maybe more. An obvious conclusion is that if the iron deposits were formed in the rocks of the pre-Cambrian Crystal Spring formation adjacent to the monzonite porphyry, they do not extend downward into the gneiss.

ORE DEPOSITS

General Description

The only metalliferous deposits thus far known or exploited in the Kingston Range are those of iron and lead. Iron deposits are known in two areas, the Beck deposit not far from Beck Spring in the valley that drains westward in the northern part of the range, and a small deposit, explored by a 10-foot drift, about half a mile west of Horse Spring. Lead deposits have been explored in the Chambers (Silver Rule) mine north of Crystal Spring; at the Blackwater mine, a mile north of Horse Spring; at the Sunrise mine, 4 miles northeast of Horse Spring; and at several prospects on a high ridge 5 miles southeast of Horse Spring. All of the lead deposits occur in the Noonday dolomite. Of nonmetallic minerals, several talc deposits in the hills several miles northeast and east of Horse Spring have been explored since 1936, and a large talc mine at Beck Spring was operating in January 1941.

Beck Iron Deposit

General Description

The distribution of outcrops of iron minerals, the claims, and the location of 14 drill holes are shown on plate XXIV. The area of this map covers three prominent spur ridges and the intervening valleys that extend southward from the high main ridge north of the main valley. The largest body of iron minerals crops out conspicuously on the western spur; no iron crops out or is known from drill holes on the middle ridge;

[illegible]

[illegible]

[illegible]

[illegible]

These observations indicate that a large plate of rocks of diverse composition, at least 20 by 30 miles in area, was thrust eastward over an extensive flat surface of erosion that was cut after lower Pliocene time. The isolated blocks briefly described above are the remnants of this plate that have survived erosion since late Tertiary time.

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two iron-ore bodies crop out on the eastern ridge. The surface exposures give little hint regarding the stratigraphic and structural complexities that are revealed by the drill cores.

Rocks and Minerals

The rocks and minerals of the iron-bearing ground fall readily into four groups: (1) unaltered carbonate rocks; (2) altered carbonate rocks; (3) oxides and sulfide of iron; and (4) igneous rocks.

(1) Unaltered Carbonate Rock. Fine-grained white limestone of the Crystal Spring formation is the most abundant sedimentary rock in the ore zone. Tests of the cores with hydrochloric acid indicate that this white rock is nearly pure calcium carbonate. In places dolomite is present in the beds of limestone but it can be detected only by the use of acid. The eastern part of the iron-bearing belt shows finely crystalline marble; but usually crystalline texture indicates the presence of appreciable wollastonite (silicate of lime) or tremolite (lime-magnesia amphibole). In general, beds of limestone form the north wall of the iron zone, as on Iron Gossam No. 2 claim.

(2) Altered Carbonate Rock. Small quantities of wollastonite and tremolite are widespread in the beds of white limestone and dolomite; these minerals seem to be most prevalent in the bed that forms the north wall of the iron zone on Iron Gossam No. 2 claim. A little diopside and garnet were found in a specimen from drill hole no. 8 (Iron Gossam No. 5 claim).

A light-brown carbonate, identified as ankerite (carbonate of iron, lime, and magnesia) is the most widespread product of alteration of the white limestone (and dolomite) in the ore zone. Drill hole no. 2 which encountered no concentrated iron-oxide minerals, passed through three layers of light-brown carbonate from 6 to 25 feet thick, separated by layers of white limestone. In addition to the solid layers of brown carbonate, veins of similar brown carbonate cut the white limestone.

Veins of pale yellowish-green serpentine were observed in light-brown carbonate near the bottom of drill hole no. 3. The serpentine appears to represent the product of the attack of silica-bearing waters upon carbonate containing magnesia and iron. At a depth of 196 feet in drill hole no. 8a, the core is a dense light-brown rock, cut by veins of white carbonate. Examination of a thin-section under the microscope shows that the brown rock is largely a felted aggregate of plates of antigorite—a variety of serpentine that contains more ferrous iron than most serpentine. It is easily confused with the brown carbonate.

(3) Oxides and Sulfide of Iron. The most abundant iron mineral is magnetite (Fe_3O_4, 72 percent iron) but considerable martite (Fe_2O_3, 70 percent iron) is present in all of the specimens examined closely. The magnetite forms massive, fine-grained lenses many feet thick, replacing the limestone; on the outcrop on Iron Gossam No. 5 claim, it forms perfect octahedral crystals as much as one inch in diameter. The martite is intimately intergrown with magnetite and local evidence indicates that it is later, and formed at the expense of the magnetite. In the logs of the drill cores the drillers distinguished between "black iron" and "red iron"; the black iron includes both the magnetite and martite.

Finely crystalline hematite (Fe_2O_3, 70 percent iron) forms lenses many feet thick near and parallel to the lenses of magnetite and martite. The drill cuttings show the characteristic reddish-brown color, and polished sections of core, though nearly black, have a reddish lustre.

M. N. Short, of the University of Arizona, has kindly examined polished sections of two specimens almost wholly made up of iron oxides, from two drill cores, and has submitted the following report:

Drill Hole No. 9; 236 feet from the surface: The ore minerals are magnetite and martite; the gangue minerals are a fibrous green mineral (probably tremolite or actinolite) and carbonate. The magnetite is black with a brownish tinge; it is replaced extensively by hematite (martite). The replacement follows gangue boundaries, in part, but both martite and hematite (scales) occur in the midst of magnetite. In this specimen the magnetite is weakly magnetic. The relations indicate that the magnetite is the earliest mineral; it is followed in order by tremolite (actinolite?), calcite, and hematite.

Drill Hole No. 9A; 336 feet from surface: The principal minerals are granular magnetite and pyrite, intimately intergrown. They are so intimately intermixed that their relations are obscure. There is no certain indication that either mineral replaces the other; they seem to have been deposited essentially contemporaneously. In most localities where magnetite and pyrite are intergrown, the magnetite is the earlier. The magnetite is strongly magnetic. Hematite is absent. Gangue minerals are calcite and a transparent mineral; both are later than magnetite and pyrite.

It seems that iron oxides (magnetite, hematite) and brown carbonate are mutually exclusive; where one mineral is present the other is absent. The evidence from the cores indicates that the large lenses of brown carbonate replace the white limestone; the same conclusion is reached for the lenses of iron oxides.

Limonite (hydrous oxide of iron) forms yellowish-brown powdery and spongy masses both on the surface and in the cores of those deposits (Iron Gossam No. 2) that contain considerable iron carbonate. Undoubtedly it is formed by the weathering of iron carbonate, even though it has been encountered several hundred feet below the outcrop. Limonite does not form bodies large enough to mine for the iron content.

Pyrite (FeS_2, sulfide of iron) is rather widespread in the deposits but concentrations are uncommon. In the drill cores, pyrite occurs widely as disseminated crystals and locally as thin veins in the lenses of both magnetite-martite and amphibole rock. A few grains are found in carbonate veins in limestone. None has been observed in the "red iron" (hematite).

(4) Igneous Rocks. The igneous rocks associated with the iron-ore bodies include an amphibole rock that occurs as sills in the iron-bearing formation, and a less abundant rock of andesitic composition that cuts the ore-bearing zone as dikes. In several drill holes, notably no. 1 (Iron Gossam No. 5), several layers of the amphibole rock are separated by lenses of "black iron", and it seems clear that the rock has been replaced by the iron oxides. The andesite dikes, on the other hand, are probably later than the iron-oxide minerals; on the surface near drill hole no. 7 and in drill holes nos. 7 and 5, a dike of reddish andesite porphyry cuts the amphibole rock and also a lens of iron oxides, which indicates that the dike was intruded after the deposition of the iron oxides.

Extent and Relations

The extent and relations of the iron deposits are revealed by outcrops, by a 300-foot tunnel and a 65-foot shaft on the Iron Gossam No. 5 claim, and by 14 drill holes. Within these claims most of the iron outcrops are prominent and rise above the level of the neighboring rocks. It is well known that in desert regions magnetite and hematite resist solution and disintegration more than most common rocks. For this reason blocks of these minerals form a surface mantle that obscures

the extent and relations of the nearby layers of amphibole rock, porphyry, and limestone. Also, the outcrops give an exaggerated impression of the thickness of the layers of iron oxides. Fortunately, the drill cores are available to show in detail the actual extent and relations of the iron minerals and nearby rocks.

Plate XXIV presents graphically the lithologic features of 11 drill cores, 6 from the western and largest iron body on the Iron Gossam No. 5 claim, and 5 from the Iron Gossam No. 2 claim. Drill cores nos. 2 and 3 are interesting geologically but as they did not encounter iron lenses, they are not presented. Neither the log nor core from drill hole no. 12 on the Iron Gossam No. 1 claim is available. In plate XXIV, magnetite (black iron) and hematite (red iron) are shown by the same symbol.

The western, or largest, iron-ore body, on Iron Gossam No. 5 claim, crops out as a prominent reef nearly 1,100 feet long. Between drill holes nos. 6 and 5, or for about 500 feet, the width of the outcrop varies from 70 to 120 feet. Drill holes nos. 6, 1, and 5 show true thicknesses of about 150, 130, and 100 feet respectively of "red" and "black" oxides, and indicate that the dip of the lens is nearly vertical. Both on the surface and at the core intersection in drill hole no. 7, the thickness varies from 30 to 40 feet, but the 40-foot lens that crops out north of drill holes nos. 8 and 8a was not encountered in either of these holes. As stated earlier and as shown in plate XXIV, drill hole no. 8 passed out of amphibole rock at 3,746 feet elevation and continued to 3,584 feet elevation in granite gneiss. As granite gneiss was encountered in drill hole no. 2 at an elevation of 3,755 feet, it is assumed that the lens of iron oxides, and also the enclosing amphibole rock and limestone, do not extend below this datum, or about 3,750 feet.

Drill hole no. 6 reached an elevation of 3,736 feet, 10 feet below the datum in drill hole no. 8, without striking granite gneiss. From what is known of this surface or datum in the Kingston Range, it appears to be approximately a plane and nearly horizontal, but it would be surprising if it did not locally depart appreciably from a perfect plane.

On the surface this ore body seems to be a single thick lens of iron oxides that lies between a thick layer of amphibole rock on the south and limestone on the north, but drill hole no. 1 recorded four layers of amphibole rock separated by lenses of iron oxides, south of the main lens of iron oxides; because of the scale, only three of these layers are shown on plate XXIV. The outcrop, drill hole no. 1, and the tunnel show that iron oxides, both as solid lenses and as disseminated grains, replace the sill of amphibole rock. The largest lens of iron oxides, however, appears to replace a bed of limestone such as that which forms the north wall of the lens.

As shown by the outcrops and drilling, the iron-ore body on Iron Gossam No. 2 claim has a more complex plan and shows more complexities in depth than that on Iron Gossam No. 5 claim. The western part of the outcrop is a single lens but eastward it splits to form two lenses; the southern appears to persist in depth, but the northern does not appear to persist. Also, in contrast with the Iron Gossam No. 5 body, these lenses dip about 70° N.

Of the five drill holes, four (nos. 9, 9a, 10, and 11) begin on the north or upper side of the ore zone and dip steeply south (70°, 70°, 70°, and 60°, respectively); the fifth hole (no. 4) begins south of the ore zone and dips 45° N., but is wholly in amphibole rock and does not

encounter iron ore. The lithology of the cores is shown on plate XXIV. In contrast to the Iron Gossam No. 5 lens, which lies between layers of amphibole rock on the south and usually limestone on the north, amphibole rock persistently forms the north wall, and some limestone, in addition to the amphibole rock, lies along the south wall. Three cross-sections (drill holes nos. 9, 10, and 11) show two lenses of iron oxides; another shows only a single lens. In three holes (nos. 9, 9a, and 10) the correlation of the cores with the surface exposures is satisfactory; in the fourth hole (no. 11), it is not satisfactory.

The thickness of the iron-oxide lens is greatest in the western part, 40 to 65 feet, but both lenses in the eastern part are thinner: the southern lens is 22 to 30 feet thick; the northern is as thick or thicker on the surface but pinches in depth.

The basement rock, granite gneiss, was not encountered in any of the drill holes on the Iron Gossam No. 2 claim. Drill hole no. 4 attained the greatest depth (elevation 3,807 feet) but was not deep enough to penetrate the gneiss (3,750 feet). No porphyry dikes were cut in any of the drill holes on this claim.

Grade

The writer examined the cores of all of the drill holes except no. 12, but did not have access to the analyses of the iron-bearing parts. As most of the cores from the iron-bearing lenses are nearly pure magnetite, martite, and hematite, which contain 72, 70, and 70 percent iron respectively, it seems probable that the iron content of the minable lenses is rarely less than 55 percent and locally exceeds 60 percent. It is estimated that the average grade of minable ore is about 60 percent iron and about 5 percent each of silica and lime. Locally, the sulfur content may reach 5 percent but the average of large tonnages is probably between 1 and 2 percent.

At the owner's request, a statement of reserves is omitted from this report. It is apparent from the data here presented, however, that the Beck deposit is among the dozen important iron deposits of the southwest and should make a noteworthy contribution of ore to the growing iron industry of southern California.

Iron Prospect

About half a mile west of Horse Spring, on the northeast side of a low hill, a 10-foot drift has explored a lens of magnetite and garnet rock about 3 feet thick in the upper part of the Crystal Spring formation. The lens lies about 75 feet west of a northeast-trending fault which separates limestone on the west from monzonite porphyry on the east. The contact-effects on the Crystal Spring formation show that the fault belongs to the intrusion epoch. The iron oxide and contact silicates are related to the monzonite porphyry intrusion.

Genesis

Local evidence is not convincing, but evidence from a large surrounding region indicates that the two groups of iron deposits on the north side of the Kingston Range are related to the monzonite porphyry intrusion of the Laramide orogeny. The iron oxides largely replace beds of limestone in the lower part of the Pahrump series of pre-Cambrian age. They also in part replace the sill-like bodies of altered syenite

(amphibole rock) that intrude the Pahrump series. It may be noted that elsewhere in this region, especially in the hills northeast of Horse Spring, large bodies of talc are found in the dolomitic limestones of the lower part of the Pahrump series adjacent to similar sills of syenite. Near Beck Spring, east of the Beck iron-oxide deposit, the presence of veins of chalcedony and also wollastonite and tremolite indicates that considerable silica has been introduced into the limestones of the Pahrump series.

Other deposits of iron oxides are known and have been exploited at several localities in southeastern California.[4] They occur under diverse environments and it seems clear that they have been formed in diverse ways and probably at diverse times. At several deposits, however, the bodies of iron oxides, commonly reported as magnetite, are found in limestone or dolomite near bodies of intrusive quartz monzonite generally regarded as late Mesozoic in age. For example, the deposits 9 miles east of Kelso, recently exploited to supply the iron furnaces at San Bernardino, present these features.[5]

[4] Hewett, D. F., and others, Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, 1936.

[5] Jones, C. C., An iron deposit in the California desert region: Eng. and Min. Jour., vol. 87, pp. 785-788, 1909; Lamey, C. A., Vulcan iron-ore deposit, San Bernardino County, California: California Div. Mines Bull. 129-F, pp. 87-95, 1945.

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO
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Iron Resources of California
Bulletin 129

PART N

Summary of the Iron-Ore Situation in California

By Ernest F. Burchard
Geological Survey, U. S. Department of the Interior

Issued by the
STATE DIVISION OF MINES

FIGURE 59. Iron-ore areas in the Western States recently studied by the United States Geological Survey, Department of the Interior. Indicated by Ernest F. Burchard, 1945.

Ore localities:

Arizona
1. Planet
2. Pikes Peak
3. Fort Apache Ind. Res.

California
1. Shasta County
2. Sierra County
3. Minarets
4. San Luis Obispo
5. Kingston Mtns.
   Iron Mtn. (Silver L.)
   Cave Canyon
   Vulcan
   Old Dad Mtns.
   Lava Beds—Bessemer
   Iron Hat
   Ship Mtns.
   Iron Age
   Eagle Mtns.

Colorado
1. Taylor Pk.
2. White Pine
3. Orient

Idaho
1. Kooskia (Clearwater)
2. Iron Mtn. (Siegwein)

Montana
1. Running Wolf
2. Thunder Mtn.
   Iron Mines Park
3. Sheep Creek

Nevada
1. Dayton
2. Lovelock

New Mexico
1. Cuchillo Negro
2. Hanover-Fierro
3. Jones Camp
4. Capitan

Oregon
1. Scappoose
2. Wild Deer

Utah
1. Mineral Point
2. Rhodes Plateau
3. Iron Springs
   Iron Mountain
   Bull Valley

Washington
1. Lynden
2. Hamilton
3. Cle Elum-Blewett
4. Buckhorn Mtn.

Wyoming
1. Seminoe Mtns.
2. Iron Mtn.
   (titaniferous)
3. Hartville

SUMMARY OF THE IRON-ORE SITUATION IN CALIFORNIA*

By Ernest F. Burchard**

OUTLINE OF REPORT

INTRODUCTION

This paper is written as a résumé of the series of reports in this bulletin (parts A-M) by geologists of the United States geological Survey. These are:

Part A—Iron-ore deposits in the eastern part of the Eagle Mountains, Riverside County, California, by Jarvis B. Hadley.

Part B—Iron Mountain iron-ore deposits, Lava Bed district, San Bernardino County, California, by Carl A. Lamey.

Part C—Iron Mountain and Iron King iron-ore deposits, Silver Lake district, San Bernardino County, California, by Carl A. Lamey.

Part D—Old Dad Mountain iron-ore deposit, San Bernardino County, California, by Carl A. Lamey.

Part E—Cave Canyon iron-ore deposits, San Bernardino County, California, by Carl A. Lamey.

Part F—Vulcan iron-ore deposit, San Bernardino County, California, by Carl A. Lamey.

Part G—Iron Hat (Ironclad) iron-ore deposits, San Bernardino County, California, by Carl A. Lamey.

Part H—Ship Mountains iron-ore deposit, San Bernardino County, California, by Carl A. Lamey.

Part I—Minarets magnetite deposits of Iron Mountain, Madera County, California, by Parker D. Trask and Frank S. Simons.

Part J—Hirz Mountain iron-ore deposits, Shasta County, California, by Carl A. Lamey.

Part K—Shasta and California iron-ore deposits, Shasta County, California, by Carl A. Lamey.

Part L—Iron ore deposits near Lake Hawley and Spencer Lakes, Sierra County, California, by Cordell Durrell and Paul D. Proctor.

Part M—Iron deposits of the Kingston Range, San Bernardino County, California, by D. F. Hewett.

The types of iron ore in the Western States, of scientific and commercial interest, are contrasted with those of the Great Lakes and Eastern United States. Comments supplementing and interpreting certain features of the several reports and of the work of the authors are offered, and the iron-ore reserves of California and their relation to the reserves of the Western States and of the nation as a whole are set forth.

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The discussion of the iron-ore reserve position affords a medium for the presentation of data on estimates of state, regional, and national reserves as of January 1, 1944, in the preparation of which the present author enjoyed the cooperation of engineers of the United States Bureau of Mines. The reader is referred to table 1 for such data.

Significant conclusions concerning the estimates of the California iron-ore reserves, as of the above date, are that the commercial (measured, indicated, and inferred) ores exceed those of any other of the 11 Western States, comprise about 30 percent of the total for the Western States and $2\frac{1}{4}$ percent of the national total. Comparatively little of the California reserve has been mined—none of it from the state's largest deposit, and the available supplies of iron ore have been shown to be ample for the operation of an iron and steel plant to a time well beyond the period necessary for its financial amortization.

GENERAL STATEMENT

At the beginning of World War I the study of deposits of ores of iron and steel-alloy metals and the encouragement of their development and production were considered of such importance that a new section was organized especially for this purpose in the U. S. Geological Survey. Much of the field work of that campaign was carried on in the Western States, and since then the Federal Survey has been on the alert for new and more complete information concerning these strategic minerals.

Between the first and second World Wars the rate at which western iron ore studies could be carried on was retarded by lack of funds but with the beginning of World War II appropriations became more nearly adequate, although the work was handicapped to a certain extent by the scarcity of qualified field geologists.

Recent work by the U. S. Geological Survey on iron ore in the West was begun with a general reconnaissance by Ernest F. Burchard and Charles Morgan, in 1940, in order to determine what deposits might merit detailed studies in the near future, and to lay the foundations for such projects. Beginning in 1941, this work developed, under the general supervision of the present writer, into systematic geologic studies of the more promising iron-ore deposits by several field parties. To the close of 1944 these examinations by the Survey comprised a total of about 50 deposits in the 11 Western States of Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. Most of the iron-ore deposits examined are in California. The several types of deposits found in the Western States represent an interesting variety of geologic features and associations.

In the preparation of reports on these studies it was essential to give primary attention to the geologic problems pertaining to drilling explorations and to summarize the geologic factors immediately affecting grade and tonnage of ore rather than to attempt comprehensive geologic studies of the areas containing the ore deposits. The work has demonstrated successful methods of appraising the extent and tonnage of iron-ore deposits by geologic work alone, and by a combination of geologic work and drilling. It is hoped that there will be future opportunity for preparation of scientific papers that will more adequately cover the geologic relations and mineralogy of the iron-ore deposits.

The feasibility of establishing an iron and steel industry in the West depends essentially on two factors, (1) the availability of sufficient

reserves of the principal raw materials—iron ore, coking coal, and fluxing stone, at reasonable costs of production, treatment, and transportation, and (2) the marketability of the products. For many years *steel* has actually been manufactured on the Pacific Coast.

There were in California in mid-1944, according to H. Foster Bain,[1] plants of the Columbia Steel Company at Pittsburg and Torrance; the Bethlehem Steel Corporation at San Francisco and Los Angeles; the Defense Plant Corporation at Pittsburg; the Judson Steel Company at Oakland; the Pacific Coast Steel Company at Niles; and the National Supply Company at Torrance; and the newly erected plant of Kaiser Company, Inc., at Fontana.

In Washington, at Seattle, an open-hearth steel plant, now owned by the Bethlehem Steel Corporation has been in operation many years, and the new plant of the Columbia Steel Company at Geneva, Utah, has entered the lists of steel producers. The older furnaces formerly operated principally on scrap and pig iron made at distant blast furnaces in the United States, and some imports during peace times from China and India. The Columbia Steel Company, prior to the recent establishment of the large steel plant at Geneva, Utah, maintained a closely integrated iron and steel manufacturing industry by shipping pig iron from its blast furnace at Provo (Ironton), Utah, to its steel plants at Pittsburg and Torrance, California. In 1924 a thorough study of raw materials available for use in a blast furnace proposed for the Puget Sound area was made by one of the steel companies. Notwithstanding the efforts that have been made to establish plants for the manufacture of pig iron in that area and at San Francisco and Los Angeles, California, no effective moves have been made to build blast furnaces at these localities.

The helpful cooperation of the California Division of Mines, represented by Dr. Olaf P. Jenkins, then Chief Geologist, is gratefully appreciated. The Mineral Abstracts prepared by the state organization, together with the general maps showing locations of mineral deposits, were of value in the reconnaissance work.

TYPES OF IRON-ORE DEPOSITS IN THE WESTERN STATES

In the Western States there are no large "ranges" of iron ore such as those in the Lake Superior region nor great basins of bedded ore such as those near Birmingham, Alabama. The deposits are, as indicated in figure 59, widely scattered. Individually they are mostly of small to moderate size, capable of contributing to established blast furnaces, but include a few relatively large ore bodies that are capable of supplying a large modern blast furnace for a period of 10 to 20 years or more.

Emphasis has been placed on the study of contact-metamorphic replacement deposits, which predominate, and modifications of such deposits. Other types of deposits of scientific and economic interest have also been studied. The ore minerals are, in the order of their abundance, magnetite, hematite, and limonite. Broadly classified on the basis of their character and geologic associations many of the deposits fall into the following types, examples of which, with their local occurrences, are cited:

Magmatic Deposits in Igneous and Metamorphic Rocks. In California, in veins and thin lenses such as the hematite-magnetite veins of

[1] Bain, H. Foster, Iron and steel: California Div. of Mines Bull. 130, p. 158, 1945.

Table 1. Reserves of iron ore in the United States, January 1944 [1]
(Millions of long tons)

Region	Percent of iron in lowest grade ore commonly mined (Fe natural, not dried)	Commercial			Potential (submarginal)	Total production (thru 1943)
		Measured and indicated	Inferred	Regional percentage of national total		
Lake Superior	51.5	1,306	500	33.0	61,000	2,076
Southeastern	35.0	1,561	561	38.7	270	325
Northeastern	25.0	535	389	17.0	1,466	163
Western	50.0	141	273	7.5	141	38
Central and Gulf	50.0	179	25	3.7	3	11
Alaska		3	4	0.1		None
Total		3,725	1,752		62,880	2,613

[1] The reserves of Potential iron ore in the southeastern United States were so greatly underestimated in 1944 that it is desired to call attention to the following publications which may serve to rectify, in part, the discrepancy:
Burchard, Ernest F., The red iron ores of East Tennessee: Tennessee Geol. Survey Bull. 16, p. 144, 1913.
Burchard, Ernest F., and Andrews, Thomas G., Iron ore outcrops of the Red Mountain formation in northeast Alabama: Alabama Geol. Survey Special Rept. 19, p. 367, 1947.

the Iron Age deposits near Dale, San Bernardino County, and the lenticular deposit of magnetite in the Minarets, Madera County; in Arizona, on Canyon and Swamp Creeks, Fort Apache Indian Reservation, as replacements of beds of quartzite and jasper near but not at the contacts of sills of diabase.

Contact-Metamorphic Replacements of Calcareous Rocks. In California, in the Eagle Mountains, Riverside County, and at several places in San Bernardino County; in Nevada near Dayton; in New Mexico at Capitan, and in southwestern Utah at Iron Springs, Iron Mountain, and Bull Valley, where replacement of limestone or dolomite by iron oxide may have been facilitated by introduction of the iron from the magma in heated gases containing ferric chloride and water.

Deposits of Sedimentary Origin. In California, bands of limonite interbedded with sandstone and shale of the Franciscan formation in San Luis Obispo County; in Oregon, limonite (bog iron ore), generally nonmetamorphosed, interbedded with flows of basalt in Columbia County; in Washington, deposits originally of ferruginous laterite, altered to magnetite and hematite through regional metamorphism at Cle Elum, Kittitas County, and at Blewett, Chelan County.

NATIONAL RESERVES AND PRODUCTION OF IRON ORE

Notwithstanding the appalling rate at which the iron-ore reserves of the United States have been depleted since the beginning of the present century, particularly in war years, no official detailed summary of the reserves of iron ore in the United States, by regions or states, was issued between 1909 and 1944. The report of 1909,[2] in which the present writer was responsible for the data on deposits in the South, was limited in its details because of the insufficiency of available information. In 1944, the Geological Survey and the Bureau of Mines, of the U. S. Department of the Interior, united in a general appraisal of the mineral reserve situation as of the close of 1943. In this work, commodity specialists of the two federal bureaus studied the available data on production, consumption, distribution, and the unmined reserves of more than 30 of the minerals of commerce upon which present industry and national defense are dependent. A summary[3] of these data in which the statistical interpretation has been expressed by means of graphic percentages was published in 1945.

If due allowance is made for the differences in bases on which the estimates of 1909 and 1944 were made, it is of interest to compare their results. In 1909 the supplies of iron ore in the United States were considered to be approximately 4,788,000,000 long tons of available ore, and 75,116,000,000 long tons of non-available ore, or a total of 79,904,000,000 long tons. The available ore of 1909 probably included some inferred ore, but as there has been considerable ore produced since 1909 the figures for that date seem fairly consistent with the measured and indicated ores of 1944 which are considered to be 3,725,000,000 long tons. The potential, or submarginal, ores of 1944 (62,880,000,000 long tons) also fell short of the non-available ores of 1909, as might well be expected.

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[2] Hayes, C. W., and others: Papers on the conservation of mineral resources: U. S. Geol. Survey Bull. 394 (iron ore, pp. 70-113), 1909.

[3] Pehrson, Elmer W., The mineral position of the United States and the outlook for the future: Mining and Metallurgy, pp. 204-214, April 1945.

In order to define the position of California iron-ore reserves in relation to those of the Western States and to those of the whole nation it seems desirable first to present the essential data on the national iron-ore reserves[4] (table 1).

Table 1 shows the iron-ore reserves of the United States as segregated into (a) material of such nature and geographic and geologic distribution as to be considered usable under prevailing economic and technologic conditions, in columns headed *Measured and Indicated,* and *Inferred,* and (b) material that may become usable under remote future conditions, in the column headed *Potential.* The potential reserves include material having an iron content of 15 to 25 percent iron, which is lower grade than is now mined in the several districts; deposits of usable grade but in beds too thin or too deep to be minable under present practices; deposits containing impurities in harmful quantities; and deposits too remote from transportation and blast furnaces for present use.

Information on which the 1944 estimates of reserves of iron ore are based was obtained in part from a study of geological and technical literature and records, and in part from recent surveys by the U. S. Geological Survey supplemented by trenching and drilling by the U. S. Bureau of Mines.

Compilation of the geologic data incidental to preparation of the tables of iron-ore reserves was largely the work of Martha S. Carr, geologist of the U. S. Geological Survey; preparation of the ore-production data was supervised by Norwood B. Melcher, mineral economist of the U. S. Bureau of Mines.

In normal times the United States can be self-sufficient in its own iron-ore reserves although there is usually a flow of imports from foreign countries such as Brazil, Canada, northern Africa, Norway, and Sweden. The steel plant at Sparrows Point, Maryland, is operated largely on ore from Cuba and Chile. Iron-ore production, which follows closely the demand for steel, is one of the first industries to show the effect of changes in industrial activity. Much of the ore is mined from open-cuts or shallow workings, where it is relatively easy to adjust operations to economic demands. Price has little, if any, effect upon iron-ore production except that periods of high industrial activity are usually accompanied by higher prices. Heavy demands for steel during major wars force iron-ore production to record levels, and the waste and destruction due to warfare diminish the proportion of scrap metal returned to the steel furnaces.

Within the United States most of the ore is produced by the companies that consume it. The principal sources are the hematite deposits in the Lake Superior region of Minnesota, Michigan, and Wisconsin, the hematite and limonite deposits in the Birmingham district of Alabama, and the magnetic deposits in the Adirondack region of New York. The Lake Superior region furnishes annually about 80 percent of the iron ore produced in the United States, or an annual output of 50 to 80 million tons, and the Mesabi Range alone, in northeastern Minnesota, produces more than half of the total annual domestic production. Most of the largest mines in the United States are on the Mesabi Range, and about half of the production is from open-pit mines. The Birmingham district during the past 10 years has produced between 3 and 7½ million

[4] Burchard, Ernest F., Johnson, Albin C., and Melcher, Norwood B., Iron ore: Manuscript report by the U. S. Geological Survey and U. S. Bureau of Mines, 1944.

long tons of hematite annually from underground mines and $\frac{1}{4}$ million to $1\frac{1}{4}$ million long tons of brown ore from open-pit mines. Mines in the Adirondack region, in New York, and at Cornwall, Pennsylvania, have produced $2\frac{1}{2}$ million to $6\frac{1}{2}$ million tons [5] of crude magnetite ore annually during the last 7 years. Utah, Wyoming, and New Mexico have yielded significant production for the iron and steel plants at Provo and Geneva, Utah, and Pueblo, Colorado, and recently there has been enlarged production from California, for the new iron and steel plant at Fontana, although some ore has been supplied to it also from southwest Utah in order to lower the average sulfur content.

Many of the deposits of the United States, some of which are in the major districts, include large quantities of material either too poor in iron or containing such a large proportion of impurities that they cannot be used under present economic or technologic conditions. The present trend indicates continued development of the major districts and the probable expansion and improvements in treatment of the lower-grade ores in them. Some of the deposits in the Western States contain sufficient sulfur to make their usability a technologic problem.

The grade of iron ore mined depends in large degree upon local conditions, both as to source and technology, and in some districts significant quantities of material are mined that would be considered sub-grade elsewhere. Table 1 shows the lowest percentage of iron in the ore commonly mined in the several regions for which reserves are calculated. It also shows the total production of ore to January 1, 1944. For Alaska, from which there has been no production, the cut-off grade for ore has been placed at 50 percent.

The total of $3\frac{3}{4}$ billion tons of measured and indicated ore implies an assured reserve equivalent to a 38-year supply even at war expanded rates of production. The total reserves of measured, indicated, and inferred ores are equivalent to about twice the total past production.

In Mr. Pehrson's review it is suggested that the estimates of mineral reserves be used with the understanding that they are subject to change even under the best of conditions, since they were attempted on such a broad scale and, therefore, represent preliminary figures only.[6]

It is pointed out that only 68 percent of the original reserves of iron ore in the United States, based on present estimates, still remains. Opinions differ as to the price at which this ore is available but it is believed that virtually all of it could be mined at prices that have prevailed in the past or at moderately higher prices. In addition to this commercial reserve there is a relatively large potential reserve of submarginal ore, principally taconites in the Lake Superior region, the utilization of which will depend on technologic advances and economic conditions. Future additions to the national reserve will depend largely on the success achieved in utilizing the known low-grade deposits not now economic to mine and the discovery of deep-seated or concealed deposits. Progress in converting submarginal resources into commercial reserves can be made through research to improve methods of extracting and processing the materials and to reduce costs. Higher prices also are an important contributing factor.

[5] All data on production of iron ore have been furnished by the U. S. Bureau of Mines.
[6] Pehrson, E. W., op. cit., p. 206.

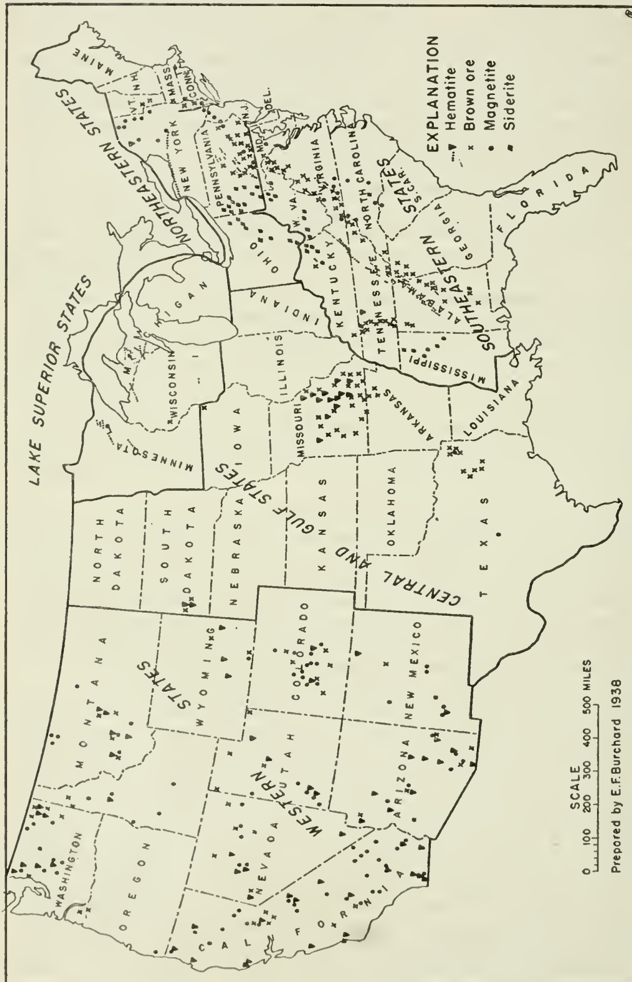

FIGURE 60. Map showing general distribution of iron-ore deposits in the United States with subdivisions for which estimates of tonnages of ore reserves are shown in table 1.

PRODUCTION OF IRON ORE IN CALIFORNIA

Prior to World War II the production of iron ore in California was relatively small because there was no large integrated iron and steel manufacturing industry within the state. Some ore was, of course, consumed in small local furnaces that had only a brief existence; some was consumed prior to the close of World War I in the experimental pig iron and ferroalloys electric smelter furnaces at Heroult, Shasta County. Considerable California iron ore has been used in smelting of nonferrous ores such as silver, copper, lead, and zinc, in the manufacture of low-heat portland cement, and in ship ballast. Finally, with the completion of the large blast furnace and steel plant of Kaiser Company, Inc., at Fontana, near San Bernardino, designed to turn out 432,000 tons of pig iron and 700,000 tons of steel per year [7] a good sized market was established for usable iron ore, and initial shipments of hematite were made from the Vulcan mine in San Bernardino County in December 1942 to the Fontana plant. The grand total production of iron ore in California through 1944, as estimated by the U. S. Bureau of Mines, is 1,919,522 long tons. The ore consisted of hematite and magnetite.

IRON-ORE RESERVE POSITION OF CALIFORNIA[8]

As shown in table 1, the reserves of commercial iron ore in the Western States on January 1, 1944, comprised about 7.5 percent of the national reserves. The reserves of commercial (measured, indicated, and inferred) ore in California, which in the preparation of the above compilation were estimated at approximately 122,658,000 long tons, exceed the estimates of reserves of any other of the 11 Western States. They comprise about 30 percent of the reserves of the Western States and 2¼ percent of the national total. Not all the deposits of iron ore in California were included in the above estimates of reserves because there are a number of known deposits about which available information is insufficient to warrant even tentative estimates. If all the known deposits could be studied intensively it seems likely that the actual totals would exceed present estimates.

A valuable paper relating to the iron and steel industry of the Western States has been written by H. Foster Bain.[9] In his discussion of the essential raw materials for making pig iron, Dr. Bain has accepted and quoted the detailed figures of iron-ore reserves originally prepared for the western and northeastern states that appear in rounded totals in table 1. The following concise summary of the iron-ore deposits in the Western States is quoted from the paper by Bain, pp. 8, 9, 10:

"In the search for war materials the Geological Survey has restudied many of the deposits, and the Bureau of Mines has drilled a number. From all these sources of information the conclusion has become clear that in the entire western region there are only three districts from which sufficient ore can, with any reasonable assurance, be expected to supply a modern steel works through or beyond the necessary period of amortization. These are the Sunrise mines in Wyoming, the Iron Mountain mines in southwestern Utah, and the Eagle Mountain mining district in southern California.

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[7] Bain, H. Foster, Iron and steel: California Div. Mines Bull. 130, pp. 155-164, 1945.

[8] This chapter was prepared as of the year 1945 when the war emergency work of the U. S. Geological Survey on strategic minerals was drawing to a close, and no attempt has been made to bring the estimates on iron-ore reserves up to date. However, later figures have been included on a recent map entitled *Iron Ore Deposits of the Western United States*, by Carl E. Dutton and Martha S. Carr, issued by the U. S. Geological Survey, as Strategic Minerals Investigations Preliminary Map 3-212, 1947, which includes not only the estimates of reserves in the 11 Western States considered herein, but also those of Texas.

[9] Bain, H. Foster, A pattern for western steel production: U. S. Bur. Mines Inf. Circ. 7315, 35 pp., March 1945.

Other mines have supplied ore in important supplementary amounts, such as the Orient mines in Colorado, the Fierro mines in New Mexico, and the Vulcan mine in California, from which last the Kaiser works now draws its supply. Still other deposits, such as those near Dayton in Nevada and perhaps others in Washington and Oregon, can be counted on for supplementary supplies; but when it comes to districts in which there is assurance of enough ore to support a modern furnace through to amortization, the choice narrows rapidly to the three already indicated. It is always possible that future prospecting or improved technology may change the picture, but in the light of present knowledge there is no reason to expect the West to be able soon to support many if any more blast-furnace plants than have now been built. If more are erected, their main reliance must necessarily be upon imported ore, and the possibility of obtaining such ore now is by no means clear. At least three localities on the west coast of Mexico can be called upon, if need be, according to reliable reports. Other deposits along the Pacific coast, in Chile particularly, are worth consideration as prospective sources of supply, so that when need arises and output justifies the necessary capital investment, ore can be brought in to feed Pacific coast blast furnaces just as at Baltimore, where at various times Chile, Cuba, North Africa, Australia, and Spain have been drawn upon. The trans-Pacific countries can supply ore to west coast furnaces, if the demand warrants the cost. So far, however, such iron supplies as have come from China and India to the United States have arrived in the form of pig iron, and future shipments would seem likely to be in the same form because of the cost of transporting ore. If large drafts on trans-Pacific sources of supply come to be made, nodulized iron may be brought in."

Postwar operation of iron and steel plants in California is now, naturally, of very great interest to the citizens of the state. It is encouraging to note that California possesses at least one of the three districts within the Western States from which sufficient iron ore may be supplied to last throughout the necessary period of amortization of a modern iron and steel plant, and this assurance is vital to the postwar continuance of activity of the Kaiser plant at Fontana. It is well also to take into account the smaller deposits described by Lamey, Trask, and Hewett, in the present series of California reports as nearly all of these deposits contain reserves that may contribute to an ore supply for Fontana. There are other supplies in the West, not mentioned by Bain, such as the large hematite deposits of the Fort Apache Indian Reservation in Arizona[10]. Suitable transportation could make this deposit an important source of ore for Pacific Coast blast furnaces. Southern California iron and steel plants can anticipate the possibility of eventually obtaining water-borne shipments of ore from areas in Mexico and Chile. Indirectly, California has an interest in the postwar continuation of the blast-furnaces at Provo and Geneva, Utah, for it is from those sources that the pig iron for the steel mills of the Columbia Steel Company near San Francisco and Los Angeles is derived.

INVESTIGATION OF CALIFORNIA IRON-ORE DEPOSITS BY THE U. S. GEOLOGICAL SURVEY

Publications by the State of California[11] indicate that 31 out of a total of 58 counties possess deposits of iron ore. The total number of

[10] Burchard, Ernest F., Iron ore on Canyon Creek, Fort Apache Indian Reservation, Arizona: U. S. Geol. Survey Bull. 821, pp. 51-78, 1931.
Stewart, Lincoln A., Apache iron deposit, Navajo County, Arizona: U. S. Bur. Mines Rept. Inv. 4093, 87 pp., July 1947.

[11] Iron: California Div. Mines, Mineral Abstracts (mimeographed), 55 pp., 1941. This report consists of material copied from the following reports and bulletins of the Division of Mines:
Bulletins: 38, pp. 298, 299, 301, 304, 305; 87, pp. 51-52; 113, pp. 34, 35; 119, pp. 44, 160, 168.
Reports: XIV, pp. 134, 516, 555-558; XV, pp. 390, 917; XVI, p. 36; XVIII, pp. 112, 188-190; XXI, pp. 162, 191, 293, 317-318, 518-522; XXII, pp. 82-84, 192, 236, 262, 335, 441; XXIII, pp. 199, 281, 297, 298, 299; XXIV, pp. 123, 336, 340, 341-343; XXV, pp. 56-57, 211-212, 218, 489-491; XXVI, p. 407; XXVII, pp. 333, 334, 335-337; XXX, pp. 62, 63, 65, 73; XXXI, pp. 330, 423-424; XXXIII, pp. 196-197; XXXIV, pp. 17-18, 424-425; XXXV, pp. 29, 159-162; XXXVI, pp. 68, 241.

deposits, or groups of deposits, in these various counties is more than one hundred. The map published by the U. S. Geological Survey in 1909[12] showing the distribution of iron ore in the United States indicates 33 separate deposits in California. Distributed by geomorphic provinces, the iron-ore deposits are chiefly in the Mojave Desert in the southeastern part of the state, in the Sierra Nevada in the east-central part, in the Klamath Mountains in the northern part, in the Coast Ranges in the western part, and in the Transverse Ranges north of Los Angeles.

SUMMARY OF CALIFORNIA IRON-ORE DEPOSITS

Riverside County

Eagle Mountains Deposits. The largest iron-ore deposits in southern California. those in the Eagle Mountains. were surveyed by Jarvis B. Hadley, assisted by Robert T. Littleton. The U. S. Bureau of Mines cooperated in drilling and in making chemical analyses during the period when the geology was being mapped. The geology had been studied previously by E. C. Harder in 1909, and for many years his report[13] served as a standard work of reference concerning the iron-ore deposits of the area. At the time of Harder's survey, the scale of mapping of such deposits was not as large, nor were the base maps as detailed, as those that are now suitable for a campaign of diamond drilling and estimation of ore tonnage. Also, the area was then much less accessible than it has been in recent years. Notwithstanding these differences, Harder's estimates of ore reserves for the whole of the Eagle Mountains, which ranged from 40,000,000 to 75,000,000 tons, are not inconsistent with the estimate by Hadley of 43,000,000 long tons of ore (28 million tons measurable, plus 15 million tons inferred ore) in the eastern part of the Eagle Mountains. Hadley's work, of course, had the benefit of definite information disclosed by the diamond drilling and chemical analyses, which sheds more light upon the classification of the ores. At any rate, it has been well established that the Eagle Mountains possess an iron-ore reserve sufficient for the support of a large modern blast furnace for many more years than the lifetime of an iron and steel plant—perhaps, as indicated by Harder, enough to supply a plant having a daily capacity of 1,000 tons of pig iron operating for more than 100 years. The ore is needed now by the newly established blast furnace and steel plant at Fontana, and railway transportation from the deposits to the plant will doubtless come in due time, through construction of track either to the Southern Pacific Railroad near Mecca, or to the Atchison, Topeka, and Santa Fe line near Rice, California.

Certain features concerning the quality of the Eagle Mountains iron ore may be of interest here. Chemical analyses show that in certain deep zones the pyrite content is greater than is desirable, although [illegible] overall average is not excessive. Gypsum, irregularly distributed [illegible]e oxidized zone and to the lowest depth explored by drill, and also concentrated in abnormally large quantities in bodies of decomposed gangue minerals, accounts for an appreciable percentage of the sulfur reported

[12] Harder, E. C., Iron ore, pig iron, and steel: Mineral Resources U. S., 1908, pt. 1, 1909.

[13] Harder, E. C., Iron ore deposits of the Eagle Mountains, Calif.: U. S. Geol. Survey Bull. 503, 81 pp., 13 pls., 1912.

in ore analyses. In the manufacture of iron and steel, sulfur present as a sulfate is reported to be less objectionable than as a sulfide. Where excessive quantities of sulfides are present the difficulty probably can be overcome by selective mining and roasting of the ore. Magnetic separation of ore from gangue does not appear feasible because hematite rather than magnetite predominates in the ore bodies.

San Bernardino County

Mojave Desert Deposits. Seven areas in San Bernardino County containing deposits of iron ore more or less irregularly distributed were surveyed during the period December 1942 to May 1943 by Carl A. Lamey, assisted by Preston E. Hotz and Stanley E. Good. The deposits are: (1) Iron Mountain, or Bessemer, in the Lava Bed district, 38 miles southeast of Barstow; (2) Iron Mountain and Iron King, about 12 miles west of Silver Lake; (3) Old Dad Mountain, about 16 miles southeast of Baker; (4) Cave Canyon, half a mile north of Baxter; (5) Vulcan, 9 miles southeast of Kelso; (6) Iron Hat or Ironclad, 6 miles north of Cadiz; (7) Ship Mountains, about 3 miles southeast of Siam.

These deposits differ slightly in details of geologic structure and associations but practically all of them possess certain features in common. Nearly all the seven deposits are of the contact-metamorphic replacement type in which iron ore, apparently derived from intrusions of monzonite, granite, syenite, or other igneous rocks, has replaced bodies of limestone or dolomite. The ore at Iron Mountain, Silver Lake, although it may have been moved to its present location during overthrust faulting, appears to have been derived from a contact-metamorphic deposit. The ore at most of the seven deposits in the Mojave Desert is chiefly magnetite, accompanied by some hematite and to a lesser extent by limonite. Much waste rock is associated with the ore at certain places. The predominance of magnetite over hematite in most of the deposits was found to be advantageous in geologic examination, because of the greater response of the dip needle.

Scarcity or remoteness of water supplies characterizes two of the deposits, so that ore-washing would be out of the question. If any of these magnetic ores are utilized in future emergencies, lower cut-off values may be tolerated in view of the possibility of electromagnetic separation.

In the preliminary report on the deposits in the Lava Bed district (Bessemer), Lamey[14] called attention to the presence of a large body of magnetite in an alluvium-covered area in the NE¼ sec. 12, T. 5 N., R. 4 E., S. B., and stated that this body might contain more ore than any other in the area. As a result of subsequent drilling of 12 or 13 deep holes by the U. S. Bureau of Mines a considerable tonnage of medium-grade magnetic ore is reported to have been inferred.

Some time after the completion of Lamey's survey of the Iron Mountain deposits near Silver Lake, the U. S. Bureau of Mines requested a larger-scale map of the principal part of this iron-bearing area. As it was not practicable for Lamey to interrupt work elsewhere, the prepara-

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[14] Lamey, Carl A., Iron Mountain iron-ore deposits, Lava Bed district, San Bernardino County, California: California Div. Mines Bull. 129, pt. B, pp. 27-38, June 1945.

A more recent report on these deposits by F. J. Wiebelt is Bessemer iron project, San Bernardino County, California: U. S. Bur. Mines Rept. Inv. 4066, 13 pp., May 1947.

FIGURE 61. Outcrop of magnetic iron ore of western ledge on Beck property, Kingston Mountains, viewed from south.

tion of this new map was undertaken by James Gilluly of the U. S. Geological Survey in March 1944. In the remapping he was assisted by J. A. Reinemund and later in the geologic work by Thomas A. Steven. When the new map was available, the Bureau of Mines bored 11 diamond-drill holes, from the logs of which Steven made estimates of tonnages, as given in Part C of this bulletin. There is little difference between the original estimates by Lamey and the later ones by Steven.

Kingston Mountains Deposits. The presence of large bodies of magnetite and hematite in a canyon on the north slope of Kingston Peak has been known for many years. They have been explored by core drills by the Pacific Coast Steel Company in 1924 and were studied by D. F. Hewett of the U. S. Geological Survey in 1924 and 1926 in connection with geologic mapping and study of the mineral resources of the Ivanpah quadrangle.

A report on these deposits has been prepared by Mr. Hewett for inclusion in this series of iron-ore reports. It is illustrated by two maps and a graphic record of cores from 11 holes drilled at the Beck iron deposit. The Kingston Range, in the northeast corner of San Bernardino County, is a rugged, nearly circular mountainous area about 10 miles in diameter, which rises from desert plains having an altitude of about 3,000 feet, to about 7,300 feet in Kingston Peak. The area is not easily accessible. It is reached by a poor desert and mountain road from Tecopa, formerly a station on the now abandoned Tonopah and Tidewater Railroad about 20 miles toward the northwest, and over a fair desert road from Jean, a station on the Union Pacific Railroad about 40 miles southeast of the range. With the removal of the rails from the Tonopah and Tidewater right-of-way, the only logical route for the transportation of iron ore to blast furnaces has been rendered ineffective.

The geologic section of the Kingston Range comprises granite-gneiss of Archean type, pre-Cambrian and Cambrian sedimentary rocks, and an intrusive igneous rock, monzonite porphyry, of late Cretaceous or

FIGURE 62. View east-southeast along strike of eastern ledge of magnetic iron ore and calcareous rock on Beck property, Kingston Mountains. At lower right of view are blocks of magnetite of the western ledge. On the eastern horizon is the head of the deep valley that drains westward to Amargosa Valley.

FIGURE 63. View westward along strike of western ledge of magnetic iron ore on Beck property, Kingston Mountains. Entrance to tunnel shows at toe of ridge at bottom of view.

early Tertiary age. The broad studies of Mr. Hewett over a long period have shed much light upon the regional geologic history, orogeny, and structure, and upon the genesis of the iron-ore deposits, and incidentally upon that of other iron-ore deposits in San Bernardino County. A most significant feature that he has recognized is that "the granite-gneiss is the basement across which there was thrust, in late Tertiary time, an enormous plate of rocks of complex composition." The altitude of this gneiss surface appears to range from 3,700 to 3,800 feet in the Kingston Range. The holes drilled in prospecting the lenses of iron ore have afforded confirmatory evidence of the surface of the gneiss over which the masses of later rocks, including those that carry the iron-ore, have been moved.

Evidence is presented showing that the entire Kingston Range is a part of this great plate of rocks that has been thrust 20 miles or more eastward and now lies in part upon pre-Cambrian gneiss and in part upon gravel, sand, and clay of middle Tertiary (lower Pliocene) age. The overthrust material comprises isolated blocks of pre-Paleozoic and lower Paleozoic sediments, largely dolomite, that have survived erosion since Tertiary time. The iron-ore bodies are found in the pre-Paleozoic sediments.

The iron-ore deposits, of which those near Beck Spring have received the most attention, are believed to be related to the monzonite porphyry intrusion of the Laramide (late Cretaceous or early Tertiary) orogeny. The iron oxides largely replace beds of pre-Cambrian limestone and to some extent replace sill-like bodies of syenite (greenstone) that intrude pre-Cambrian rocks. The ore bodies are massive lenses, one of which crops out as a prominent reef nearly 1,100 feet long. Considerable pyrite occurs with the magnetite and some iron carbonate and limonite are present but are not of value as ores. The general mineralogical features of the deposits are similar to those of other contact-metamorphic deposits of magnetite and hematite in southern California.

No analyses of the ore from outcrops or drill cores are available, but examination of the cores indicates that most of them are nearly pure magnetite, martite, and hematite. It is estimated that the average grade of the minable ore would carry about 60 percent iron with about 5 percent each of silica and lime. Locally the sulfur content may reach 5 percent, although the average of large tonnages would probably be 1 to 2 percent.

Observations by Morgan and Burchard during a few hours' inspection of the deposits near Beck Spring in January 1941, showed that the black ore on the outcrop and in the tunnel was generally fine-grained, dense magnetite of high purity. The sporadic occurrences of coarsely crystalline pyrite in the lower part of the 65-foot shaft, however, appeared a little disconcerting.

The data presented by Mr. Hewett indicate that the Beck deposit, the largest of the Kingston groups, is among the dozen important iron-ore deposits of the Southwest and could make a noteworthy contribution to the growing iron industry of southern California. The paper on the iron ores of the Kingston Range is a welcome addition to the series of reports on the iron resources of California. It is the first paper to record the results of a detailed investigation of the Kingston deposits and it gives interesting and significant data on the problem of the great overthrust fault of the late Tertiary orogeny, traces of which may be

recognized in several places southeast of Death Valley, probably including the blocks of iron ore at Iron Mountain west of Silver Lake. A report on the Silver Lake district has been written by Lamey.[15]

Madera County

Minarets Deposits. The Minarets magnetite deposits of Iron Mountain, Madera County, were studied by Parker D. Trask and Frank S. Simons of the U. S. Geological Survey in August 1942. Public interest in these deposits dates back before World War I, but the second World War brought about the exploration by the U. S. Geological Survey and U. S. Bureau of Mines.

The Minarets iron-ore deposit is unusual in several respects as indicated by the authors of current reports.[16] The deposit is near the crest of the Sierra Nevada, 100 miles by road and trail northeast of Fresno. The final 18 miles to the deposit must be traveled on horseback over a steep, rugged trail from the nearest automobile road at Red Meadows Ranger Station. The surface features of the region, which is described by those who have visited it as one of rugged grandeur and striking rock sculpture, are shown on the topographic map of the Mount Lyell quadrangle, published by the U. S. Geological Survey. The altitude, between 10,000 and 10,500 feet, is one of the highest at which any iron deposit of considerable size has been found in California. The deposit is in the form of a wedge embedded vertically along the strike of the enclosing rocks, which is about N. 14° W. The country rock is meta-andesite intruded by plutonic rocks of which granite forms a part. Along its axis the deposit measures about 1,400 feet and at right angles to it the maximum thickness is about 160 feet. Vertically the ore extends to about 650 feet but its thickness and quality diminish with depth. Deposition of the ore body has probably been controlled by a fault or shear zone. Unlike many of the other iron-ore deposits in California, no limestone or dolomite are reported to be present and all evidence points to a direct magmatic replacement rather than contact-metamorphic origin. In certain features the Minarets deposit resembles the magnetite at Cranberry, North Carolina, and may have had a similar origin.[17]

The surface ore of the Minarets deposit consists of sheet-like masses of (1) nearly pure magnetite and (2) mixtures of magnetite and actinolite. Since the mixed ore may contain as much as 50 percent by volume of actinolite, it is possible that in early reconnaissance investigations the actinolite may have been mistaken for magnetite, and the reserves of high-grade ore consequently over-estimated. Petrographic work by Trask and drilling by the U. S. Bureau of Mines have, fortunately, cleared up many uncertainties as to the quality and quantity of ore in this deposit.

Analyses of typical composite samples taken by Trask show that the average composition of the ore body at the surface is 60 percent iron and 8 percent silica. The highest iron was 65 percent and the lowest was 50.10 percent; the silica ranged between 4.10 percent and 15.9 percent.

[15] Lamey, Carl A., Iron Mountain and Iron King iron-ore deposits, Silver Lake district, San Bernardino County, California: California Div. Mines Bull. 129, pt. C, pp. 41-56, June 1945.

[16] Trask, Parker D., and Simons, Frank S., Minarets magnetite deposits of Iron Mountain, Madera County, California: California Div. Mines Bull. 129, pt. I, pp. 119-128, June 1945.

Severy, C. L., Exploration of the Minarets iron deposit, Madera County, California: U. S. Bur. Mines, Rept. Inv. 3985, 12 pp., December 1946.

[17] Bayley, W. S., Magnetic iron ores of east Tennessee and western North Carolina: North Carolina Geol. Economic Survey Bull. 32, pp. 68, 69, 1923.

An average content of about 0.35 percent phosphorus is cited as the most deleterious component of the ore. Some part of the phosphorus is believed to have been derived from the mineral apatite.

Log and core analyses of holes 1 and 2 drilled by the U. S. Bureau of Mines are more revealing as to subsurface composition and thicknesses of beds of ore and associated rocks. The core recovery of hole 1 averaged 97.3 percent. From a depth of 187.5 feet to 354 feet the iron content of the core ranged from 21.6 to 64.2 percent, averaging 42.4 percent; the silica content ranged from 2.98 percent to 29.06 percent, and the phosphorus content averaged 0.50 percent. Core recovery of hole 2 averaged 83.7 percent; the mineralized portion of the hole averaged less than 30 percent iron, and the phosphorus content of the mineralized bands ranged from 0.06 to 1.11 percent. An analysis of a mixed sample of the core and sludge from both holes gave the following percentages: Fe, 33.5; insoluble, 41.2; SiO_2, 23.7; S, 0.01; P, 1.29; CaO, 7.8; MgO, 6.0; Al_2O_3, 6.1. Comments by the U. S. Bureau of Mines [18] are as follows:

"It is evident from the data obtained that the grade of the deposit at depth is considerably lower than is indicated by the high-grade outcrop. Massive magnetite occurs in comparatively narrow bands, and the deposit contains more numerous bands of low-grade ore and waste than are noted on the surface. The average grade of the ore over minable widths is too low for direct blast or open-hearth furnace feed. Should large-scale mining operations be considered, the ore as mined would require beneficiation before a product suitable for direct smelting could be obtained.

"Magnetic separation proved only moderately successful in beneficiating the ore, principally because much of the magnetite is locked with gangue at plus 20-mesh sizes. However, by treating unsized minus 6-mesh ore a recovery of 72 percent of the iron was made in a concentrate assaying 51 percent iron, 20 percent insoluble, and 0.62 percent phosphorus. Over 23 percent of the iron concentrated in a middling product assayed 37 percent iron. Other tests indicated grinding to about 48-mesh will be required to obtain liberation of the phosphorus-bearing mineral."

Estimates of tonnages of iron-ore reserves in the Minarets deposit have varied greatly. Some probably have been justified by the observed facts, while others apparently have been too optimistic. A few of the estimates made within the past 35 years and classified according to recent practice are given in the following table:

Estimates of iron-ore reserves in long tons in Minarets deposit, Madera County, California

Author	Measured	Indicated	Inferred	Potential	Remarks
Weeks, F. B.[1]			30,000,000	Possibly some additional	
Dougherty, E. Y.[2]	1,000,000 (in sight)	7,000,000 to 10,000,000		Possibly much additional	
Erwin, H. D.[3]		5,000,000 to 10,000,000			Includes 20 percent impurity.
Trask, P. D., and Simons, F. S.[4]	2,500,000		2,500,000	2,000,000 (border zone)	

[1] Weeks, F. B., California Div. Mines, Rept. 14, pp. 555-558, 1913-14.
[2] Dougherty, E. Y., Eng. and Min. Jour., vol. 123, May 7, 1927, pp. 765-770.
[3] Erwin, H. D., California Div. Mines, Rept. 30, pp. 62-65, 1934.
[4] Trask, P. D., and Simons, F. S., California Div. Mines Bull. 129, pp. 119-128, 1945.

Mining problems would be simple. According to Dougherty[19], "Many million tons can be removed through one or more tunnels before sinking would become necessary. Direct attack by open-cuts and removal of several million tons is possible with no preliminary development work

[18] Severy, C. L., op. cit., pp. 9, 12.
[19] Dougherty, E. Y., op. cit., pp. 769-770.

whatever. No waste overburden is present. More favorable conditions for cheap mining of the surface or near-surface ore would be difficult to find. These factors help to offset the most adverse factor to be met in exploiting the deposit—namely, the long snow season . . . even in early July of some years snow covers portions of the outcrop and surrounding slopes."

As to transportation problems, Dougherty says: "The nearest railroad connection to Pacific Coast consuming centers is near Bass Lake in the west foothills of the Sierra Nevada, an airline distance of about 30 miles and a drop in elevation from about 10,500 feet at the mine to about 3,500 feet near Bass Lake. The first 3,000 to 4,000 feet of drop can readily be accomplished by an aerial tram. . . . Based on present ore in sight, railroad construction cost to Bass Lake or the vicinity will be excessive and not justified."

From what is now known as a result of the recent Federal investigations, the conclusion reached by Mr. Dougherty still appears to be valid. Only in an emergency through which the value of iron ore might be so greatly enhanced that the cost of aerial tram and railway would be justified is it likely that the Minarets iron-ore deposit will ever be utilized.

Shasta County

Hirz Mountain, Shasta and California Deposits. In the summer of 1944 iron-ore deposits in the Klamath Mountains of Shasta County were surveyed by Carl A. Lamey, assisted by Paul D. Proctor. These deposits comprised: (1) the Hirz Mountain deposits, about 24 miles N. 20° E. of Redding; and (2) the Shasta and California deposits, about 12 miles north of Redding.

Geologic conditions in all the deposits are similar, though the Hirz Mountain deposits fall far behind the Shasta and California deposits in development and production. It seems likely that fragments of iron ore scattered down the slopes of Hirz Mountain have created an erroneous impression of the extent of the deposits, and given rise to rumors that were not substantiated by scientific examination.

Shasta County has long been reputed to possess deposits of iron ore that might be depended upon either to support or contribute to an iron industry in northern California. In fact, the ores of the Shasta Iron Company's properties actually did support from 1907 until the close of World War I, with the aid of electric power, the experimental manufacture of both pig iron and ferroalloys. It was the privilege of the author to inspect in 1912 and 1913 the experimental electric furnaces at Heroult, then operating on pig iron.

The Shasta iron-ore deposit is large and massive, consisting of limonite on the surface and magnetite below. The deposit was worked as a quarry; the ore was shot down and conveyed to the smelter, half a mile distant, by means of an automatic tramway. A technically successful method of electric smelting of ores of iron and alloy metals was followed at Heroult by the Noble Electric Steel Company for several years. This company mined under lease the properties of the Shasta Iron Company. The electric smelting plant has been idle since World War I, but the processes used for producing charcoal pig iron, and later ferromanganese and ferrosilicon, are of value technically and economically, indicating the possibilities for such an industry in the future. The products of this plant were of high quality but operations

were costly. Contrary to expectations, the cost of the large quantity of electricity required was too high to make the process a financial success in normal times.

The plant was built about 1907 and until 1917 produced pig iron. Charcoal, barren quartz, limestone, and iron ore from the Shasta Iron Company's claims were charged together into the furnace, and a superior quality of pig iron, very low in sulfur and phosphorus and carrying from 1 to 5 percent silicon was obtained. The daily capacity, with a crew of 12 men, was 25 tons. Each of the four carbon electrodes used 1500 kilowatts of electricity. After World War I started, the making of ferromanganese and ferrosilicon was begun. The manganese ore used was from mines in various parts of California and the iron ore was the highest grade produced locally. For several years after the closing of the electric furnace plant considerable quantities of iron ore were shipped from the Shasta deposits to steel furnaces on the Pacific Coast and until recently these deposits have been the principal producers of iron ore in California. Further historical details as to the ore deposits, electric furnaces, raw materials used, and the smelting processes are given in certain Division of Mines reports[20].

An estimate of ore in the Shasta deposits, cited in 1926, was 1,000,000 tons[21]. This may refer to the highest grade ore, such as that mined for making electric pig iron and ferroalloys, which ore carried 58 to 68 percent of iron. Lamey's estimates indicate a total of 4,680,000 tons of ore carrying an average of 37.82 percent iron as indicated by analyses of 428 feet of cores drilled by the U. S. Bureau of Mines, prior to the geologic investigation.

Sierra County

Spencer Lakes and Lake Hawley Deposits. Several small deposits of magnetic iron ore, in two groups near the Spencer Lakes and Lake Hawley, about 10 miles northeast of Downieville, Sierra County, were studied in the summer of 1945 by Cordell Durrell and Paul D. Proctor of the U. S. Geological Survey. The writer has not seen these deposits.

The ore deposits are in the Calaveras formation which consists of metamorphic rocks, for the most part of Carboniferous age, that have been derived from fine sandy sediments, mixtures of calcareous and clastic sediments, cherts, tuffs, and tuff breccias. Most of the deposits consist of magnetite and talc, apparently having originated through the replacement of clastic sediments, tuffs, and lamprophyre dikes. Other deposits consist of magnetite and calcite and have been formed by replacement of dolomite. The ore bodies are small, irregular to lens-like masses, most of them being only a few feet long. Five deposits of the Spencer Lakes group are within an area 50 by 120 feet. The area of the largest body in the Lake Hawley group is roughly 180 by 200 feet. Although all the deposits are obviously of greater scientific than economic interest, it was essential that the grade of the ore be determined and that the areal geology, mineralogy, and structure of the local rocks be studied critically in order that the geologic occurrence of the deposits be clearly outlined and their probable vertical extent be determined.

The geologic relations of all the ore deposits are complicated; the deposits are separated from the surrounding rocks by fractures, faults, previously existing contacts between contrasting rocks, and sharp grada-

[20] California Div. Mines Rept. 14, pp. 805-806, 1914; 22, pp. 190-192, 1926.
[21] California Div. Mines Rept. 22, p. 192.

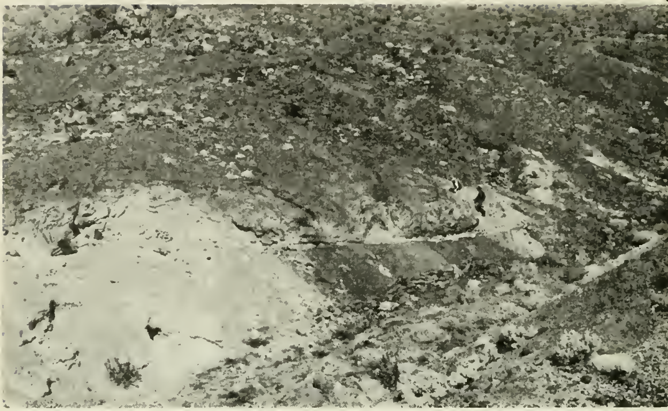

FIGURE 64. View of prospect cut and tunnels at Mister deposit of specular hematite on north side of small branch of Confidence Wash, about 18 miles west of Shoshone, Inyo County.

tions. The ore deposits are believed to be of hydrothermal origin, and those of the Spencer Lakes group, particularly, to be genetically related to a metamorphosed diorite intrusive and its associated dikes. The mineralizing solutions apparently rose along a contact between dolomite and other sediments and the magnetite was deposited on both sides of the contact. The ore deposits themselves have been dynamothermally metamorphosed, and are older than the Nevadan orogeny.

Partial chemical analyses of three samples from the Spencer Lakes deposits showed an average of 38.77 percent of metallic iron. Only low percentages of deleterious substances such as titanium, phosphorus, and sulfur are shown. Seven samples from the Lake Hawley group were studied under the microscope to determine the grade of these ores, and no important minerals besides talc and magnetite were found. The authors conclude that the average content of magnetite and of iron will probably not exceed 30 percent and 21 percent, respectively.

The magnetic survey of the Lake Hawley deposits disclosed no important extensions of the main bodies of magnetite, and the shapes of the lines of equal dip-needle inclinations correlate well with the outlines of the outcrops. In one instance, areas of both high and low intensity were susceptible of fairly definite interpretations. The magnetic work was systematically and carefully performed, but unfortunately, only a "pipe-finder" dip-needle was available.

From the data gathered at three deposits in the Lake Hawley group there was first estimated the total tonnage of magnetite per 10 feet of depth for all possible areas. This total amounted to 16,700 tons, and if the average continuation in depth should be as much as 100 feet, the sum total would probably not exceed 167,000 tons. In the Spencer Lakes group, each of the 13 areas of outcrop was assumed to be a separate ore body. Using such factors as were pertinent to the various deposits the estimated tonnages ranged from negligible to a maximum of 3,117 tons, or a total for the whole group of 8,206 tons. The maximum

tonnage of ore in both groups of deposits would therefore scarcely exceed 175,000 tons, which constitutes, in the words of the authors, "at most only a tiny reserve of iron ore."

Inasmuch as the country is rugged, the deposits are difficult of access, and much of the ore would have to be subjected to magnetic concentration, this report holds no encouragement toward commercial development of the deposits.

San Luis Obispo and Inyo Counties

During a reconnaissance in 1940-41, the author, accompanied by Charles Morgan, examined a number of iron deposits other than those described in this bulletin. These included deposits in San Luis Obispo and Inyo Counties.

Prefumo Deposits. The San Luis Obispo County iron deposits include beds of limonite and hematite in the shales and ferruginous sandstones of the Franciscan formation of Jurassic (?) age. They are described in several reports of the California State Division of Mines.[22]

Raven and Mister Mines. Reported deposits of iron ore in Inyo County west of Shoshone were also visited by Charles Morgan and the author. Among these are the Raven mine and the Mister mine, respectively about 11 miles and 14 miles airline southwest of Shoshone. Both deposits can be reached from the county highway that extends from Shoshone to Jubilee Pass in Death Valley. The Mister mine, at which most work had been done, is on the border of the Death Valley National Monument about 1 mile south of the highway and $1\frac{3}{4}$ miles east of Bradbury Well.

The deposits consist of soft, fine-grained, dull bluish-gray, powdery hematite sparsely disseminated along the planes of a granite gneiss. The rock weathers to a soft, crumbly material, yielding the bluish-gray powder. In places the mineral is more or less concentrated in pockets and in others the rock is nearly barren. From the pockets small quantities of the hematite have been recovered and shipped in sacks to Los Angeles for use as coating for welding rods. The following analyses by the U. S. Geological Survey of fairly high-grade material are available.

Analyses of iron oxide powder from Inyo County, California

	Mister mine	Raven mine
SiO_2	11.14	17.20
Al_2O_3	6.08	10.80
Fe	56.84	44.99
MgO	0.20	0.19
CaO	0.16	2.96
TiO_2	0.10	0.10

The ore is of mineralogical interest but the deposit does not appear to meet the quantitative requirements of a source of supply of iron ore for a blast furnace. The powdery material is essentially nonmagnetic and could not be concentrated economically.

[22] Reports 5, p. 99; 6, pp. 114, 118; 15, pp. 688-689; 18, p. 112; 21, pp. 515-522; 31, pp. 423-425.

STATE OF CALIFORNIA
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PART O

Summary of Investigations of the Iron-Ore Deposits of California

By A. C. Johnson and Spangler Ricker
Bureau of Mines, Department of the Interior

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SUMMARY OF INVESTIGATIONS OF THE IRON-ORE DEPOSITS OF CALIFORNIA *

By A. C. Johnson ** and Spangler Ricker ***
United States Department of the Interior, Bureau of Mines

OUTLINE OF REPORT

INTRODUCTION

In accordance with a request by Congress for an investigation of raw materials for the production of steel, an iron-ore survey of the State of California was made by the U. S. Department of the Interior, Bureau of Mines. This was part of the general survey made of the whole United States and its possessions. Field work was begun in 1941 and continued intermittently through 1945.

An endeavor was made to examine and report on all properties known to the Bureau or that were brought to its attention and which, from data on hand or presented, appeared to justify the expense of an examination. Particularly investigated were all deposits that were thought to have commercial tonnages suitable for the established steel industry or judged likely to fit into any new postwar use pattern.

More than 100 examinations were made, and five of the most attractive deposits were chosen for exploration by means of diamond drilling, trenching, sampling, and a minor amount of underground work. Magnetometer surveys of four areas also were made.

Massive sulphide deposits were investigated only in relation to the oxide gossans which at a few places amount to appreciable tonnages. Beach sands were eliminated as a possible source of iron ore within the scope of the survey.

Experimental metallurgical work was done on numerous samples from various parts of the State to gain knowledge of the adaptability of the ores for commercial use.

ACKNOWLEDGMENTS

This paper is a brief summary of the investigations of iron-ore deposits of California made by the Bureau of Mines, U. S. Department of the Interior, during World War II.

The work was done under the auspices of the Mining and Metallurgical Branches, of which Lowell B. Moon and R. G. Knickerbocker are the respective chiefs. Work of both branches is integrated under the supervision of Dr. R. S. Dean, Assistant Director of the Bureau of Mines.

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Field exploration was under the direction of Frank Wiebelt, C. L. Severy, John R. Shattuck, and W. D. McMillan. Examinations were made by D. W. Butner, C. L. Severy, and W. H. King. Metallurgical work was under the supervision of S. R. Zimmerly and done principally by A. C. Rice, H. G. Poole, H. D. Snedden, and their assistants. Full details of their work have been described in various special papers.

Special acknowledgment is made to W. W. Bradley and the staff of the State Division of Mines for their assistance and cooperation in this as well as other work undertaken in California by the Federal Bureau of Mines.

Appreciable assistance was also obtained from work of the Geological Survey, U. S. Department of the Interior.

EXPLORATION

The following properties were chosen for exploration, and development work was done as indicated in the following table.

Exploration and development of properties by U. S. Bureau of Mines

Property	*County*	*Diamond drilling (ft.)*	*Trenches, (linear ft.)*	*Drifts and crosscuts, (linear ft.)*
Eagle Mountains	Riverside	14,578	6,732	535.5
Iron Mountain	San Bernardino	1,620		
Bessemer	San Bernardino	4,230		
Shasta Iron	Shasta	2,910		
Minarets	Madera	1,056		
Totals		24,394	6,732	535.5

Owing to the physical character of the formations in which the iron deposits occur, core and sludge recoveries were low. The core recovery ranged from 9.7 percent on the brecciated Iron Mountain deposit to 83.7 percent at the Minarets. Core and sludge recoveries from all deposits averaged 31.8 percent and 69.7 percent, respectively. The weighted average assay checked very closely with the sections in the various properties where surface and underground samples could be taken.

The 24,394 feet of drilling consisted of the following sizes:

Size of holes, feet

Nx	Bx	Ax	Ex
976	2,156	9,600	11,662

The estimated total reserve of measured, indicated, and inferred ore on the properties drilled is 105,000,000 tons, with a 40-percent iron content or better. Of this amount, 28,000,000 tons with more than a 50-percent iron content could be selectively mined. In addition to these tonnages, probably 25,000,000 tons of ore is available on other properties examined but not explored by the Bureau.

Of the total reserves, approximately 30 percent are adaptable for direct blast-furnace or open-hearth feed. Beneficiation of the balance would be required to yield a commercial product.

The estimates are based on depths to which it is thought economical mining could be carried under normal conditions. Tonnage estimates

will, however, change from time to time as properties are explored and developed.

Magnetometer surveys were made on the Shasta, Iron Mountain, Bessemer, and Hotaling properties.

ORES

The iron minerals in the California ores are principally magnetite and hematite. Some limonite occurs in a few deposits as the chief mineral, but the limonite ores make up only a small percentage of the reserves of the State. Probably 80 to 90 percent of the deposits are of the contact-metamorphic type and occur as replacements of limestone or dolomite near contacts with granitic intrusives. The rocks in the ore areas have been highly metamorphosed.

MINING METHODS AND COSTS

Most of the large deposits in California could be exploited by low-cost, open-cut mining methods. Mining and crushing costs for the direct-shipping ore, loaded into stockpile or bins at the mine for shipment to blast furnaces, would range from $0.65 to $1.00 per ton based on a 2,000- to 5,000-ton daily production.

There would be an additional cost of $0.40 to $0.75 per ton of concentrate for the ore that required beneficiation.

METALLURGY

More than 2,500 samples were collected and analyzed by the Bureau of Mines laboratories. Beneficiation tests were made on bulk samples from some of the larger deposits.

The undesirable minerals in the California ores are phosphorus, sulfur, and silica. Certain minor deposits contain 1 to 4 percent manganese and some near Los Angeles contain 15 to 20 percent titanium dioxide (TiO_2) and as much as 0.5 percent vanadium pentoxide (V_2O_5). Sulfur content ranges from 0.001 to 1.2 percent in the larger deposits of the State and generally increases in depth owing to increased percentages of pyrite. Phosphorus content is 0.003 to 0.40 percent elemental phosphorus in the magnetite and hematite deposits, with the exception of the Churchill ore in Mono County, which average 0.75 percent; phosphorus content of some of the limonite ores is as high as 0.65 percent. Silica (SiO_2) content is 3 to 5.5 percent in the desirable ores of San Bernardino County and seldom more than 15 percent in the lower-grade ores.

Available analyses indicate that approximately 40,000,000 tons of estimated reserves of 52-percent iron content are suitable for direct blast-furnace feed. A small percentage of this total is, however, in inaccessible districts where production in the near future will not be economical.

Metallurgical tests have shown that a great part of the 40-percent iron ore can be brought to suitable grade for use in established steel practice when it is economical to do so.

The future of the small deposits will depend upon the development of a new use-pattern in which they can be utilized in conjunction with other raw materials available in the vicinity, for the manufacture of special materials and alloys.

Typical analyses of some of the ores, with comments on beneficiation tests, are given below.

EAGLE MOUNTAINS DEPOSITS

Several samples were analyzed for barium, tungsten, and vanadium, all of which were absent. Only traces of gold and silver were found. Nickel, chromium, and arsenic are present in amounts less than 0.005 percent, and the highest percentage of titanium oxide was 0.12.

The principal iron minerals in the Eagle Mountains ores are hematite and magnetite. Near the surface and in the upper 100 feet of the ore beds, hematite predominates over magnetite in the ratio of 5:1, but at depth magnetite, generally associated with pyrite, is the principal ore mineral. The gangue minerals consist of serpentine, tremolite, gypsum, and minerals of the mica and chlorite groups.

Analyses of iron ore from Eagle Mountains deposits

	A	*B*	*C*	*D*	*E*	*F*	*G*
Fe	64.4	48.6	54.7	48.9	50.4	53.5	50.6
Insol.	2.8	5.0	10.6	5.0	--------	--------	--------
SiO_2	2.2	3.6	8.7	3.8	11.37	8.46	11.46
S	1.1	4.1	Nil	Trace	0.28	0.09	0.04
P	0.009	0.014	0.033	0.016	0.05	0.012	0.015
CaO	0.6	8.8	0.9	8.1	1.78	2.35	1.95
MgO	0.36	1.45	4.31	6.1	3.00	2.12	5.67
Al_2O_3	0.7	1.7	1.9	1.1	--------	3.70	1.89
Mn (less than)	0.05	0.05	0.05	0.05	--------	--------	--------
Co	0.01	0.01	0.01	0.02	--------	--------	--------
Cu	0.05	0.08	0.05	0.05	--------	0.62	--------
Pb	Nil	Nil	Nil	Nil	--------	--------	--------
Zn	Nil	Nil	Nil	Nil	--------	--------	--------

A—Pyritiferous high-grade ore from main deposit.
B—Massive hematite mixed with gypsum from southern deposit.
C—Hematite, magnetite, and serpentine from southern deposit.
D—Hematite and lime-silicate rock from southern deposit.
E—Drill hole 9—sludge composite, main deposit.
F—Drill hole 19—sludge composite, southern deposit.
G—Drill hole 45—sludge composite, Bald Eagle deposit.

When lot A was crushed to pass a ½-inch screen and sintered, the high sulfur content was reduced to less than 0.20 percent, and the iron content brought up to 68 percent.

With lots B, C, and D, recoveries of 83 to 92 percent were obtained of products assaying over 60 percent iron and less than 0.20 percent sulfur. This was accomplished by the simple procedure of crushing the ore to pass 1½-inch, screening on 10-mesh, and treating the coarse portion by the sink-float method.

Additional recoveries of 3 to 9 percent from each of the samples were obtained by tabling the undersize of 10-mesh after further sizing at 20- and 30-mesh.

Ores similar to lots B and C probably could be treated at a size coarser than 1½ inches without seriously diluting the concentrates with gangue, but that represented by lot D, in which the gangues and iron minerals are associated more intimately, probably can not be beneficiated at a coarser size.

IRON MOUNTAIN DEPOSITS, SILVER LAKE DISTRICT

Mineralogically, the Iron Mountain iron minerals are magnetite and a minor amount of hematite. There has been some oxidation of the magnetite to limonite. The principal gangue minerals are impure calcium and magnesium carbonates, orthoclase, quartz, and gypsum.

Hydrogen reduction roasts followed by magnetic separation gave plus 98-percent recoveries of iron and a low insoluble content of less than 2.0 percent with only 8-mesh crushing. Since magnetite was the principal iron mineral in the Iron Mountain samples, Davis-tube magnetic separation tests were made on oxide ore for comparison with results obtained on roasted material. Owing to the presence of some hematite and limonite in the ore, recovery of iron in the magnetic portion of unroasted ore was 8 to 13 percent lower than from reductively roasted material. The higher losses occurred in the finer sizes, possibly owing to greater liberation and sliming of limonite. However, liberation of gangue was excellent at 8-mesh sizes. Minus 8-mesh magnetic concentrates from oxide ore assayed less than 2 percent insoluble and 1 percent silica, with losses of only 7 to 10 percent of the total iron. It is doubtful if the small additional recoveries to be obtained by inclusion of a reducing roast before magnetic separation would justify this extra step.

Analyses of iron ore from Iron Mountain deposits (Silver Lake)

	A	*B*	*C*	*D*
Fe	58.8	57.2	55.6	54.2
Insol.	3.9	2.7		
SiO_2	2.6	1.7	5.9	6.73
S	0.01	0.01	0.13	0.087
P	0.03	0.03	0.014	0.012
CaO	5.6	8.2	4.04	4.49
MgO	2.0	1.2	2.58	2.41
Al_2O_3	0.9	0.8	2.32	2.94
Mn	0.1	0.1	0.05	0.05
Cu	0.06	0.02		
Pb	0.05	0.05		
Zn	Nil	Nil		
TiO_2	0.05	0.05		

A—Surface samples, north outcrop.
B—Surface samples, south outcrop.
C—Ore indicated by diamond drilling.
D—Ore inferred by diamond drilling.

BESSEMER DEPOSIT, LAVA BED DISTRICT

The predominating iron mineral in the Bessemer deposit is magnetite, dispersed in a fine-grained calcium-magnesium-silicate gangue rock. Minor amounts of hematite occur, particularly in diamond drill hole 13. The magnetite is found in areas as large as a quarter of an inch and as small as 300-mesh. These areas are not composed entirely of magnetite but contain 10 to 20 percent gangue materials. Most of the magnetite grains fall in the range of 20 to 150-mesh. Larger areas, fairly rich in magnetite, are present, not as grains but as collections of grains intermixed with gangue.

Analyses of iron ore from Bessemer deposit, Lava Bed district, sec. 12, T. 5 N., R. 4 E.

	A	*B*	*C*	*D*
Fe	32.6	43.7	39.5	37.32
Insol.	47.4	32.5	32.5	----------
SiO_2	26.9	16.7	17.6	16.58
S	0.03	2.0	1.2	1.05
P	0.13	0.02	0.02	0.033
CaO	10.8	8.5	9.3	7.43
MgO	7.0	6.2	5.7	7.48
Al_2O_3	4.7	3.7	4.8	5.23
Mn	0.25	0.2	0.2	0.13
Cu	0.03	0.03	0.04	----------
Pb	0.1	0.1	0.10	----------
Zn	0.1	0.1	0.1	----------
TiO_2	0.12	0.1	0.1	----------

A—Channel samples from 50 foot Kaiser shaft.
B—Average core analysis diamond-drill holes 2-3-7.
C—Average sludge analysis diamond-drill holes 2-3-7.
D—Adjusted core and sludge analysis all ore sections.

The gangue rock is very fine grained, consisting chiefly of aggregates of minute crystals, tentatively identified as diopside. A lesser amount of epidote is present, as is also a minor amount of calcite.

In lot A, which is probably typical of the ore that would be mined, very few of the magnetite grains are present in localized clusters. Most of them are uniformly distributed throughout the gangue.

A coarse gravity-beneficiation test was conducted on ore crushed to minus 2 inches. The plus 10-mesh fraction was concentrated by tabling.

The only product that assayed over 48 percent iron was the small quantity of minus 20-mesh table concentrates. The over-all recovery was 65.5 percent in a product assaying only 38.9 percent iron, 21.2 percent SiO_2, and 0.01 percent sulfur. The plus 10-mesh product which made up bulk of concentrates assayed only 36.2 percent iron.

Since only the minus 10-mesh ore gave any great degree of liberation, the second test treated ores ground to minus 10-mesh, by jigging and tabling methods. The plus 20-mesh jig tailings were ground to minus 20-mesh and re-treated. A recovery of 70.3 percent was obtained in a product that assayed 51.2 percent iron and 13.7 percent SiO_2. By regrinding the table tailing to minus 48-mesh and re-treating, the recovery was increased to 81.8 percent in a combined concentrate that assayed 51.9 percent iron and 13.2 percent SiO_2.

Since the above gravity concentrates would require sintering, an attempt was made to return to coarse sizes of separation. In the following test, ore was crushed to minus $\frac{1}{4}$-inch and screened on 8-mesh. Both fractions were treated in a laboratory model of a D. C. field magnetic separator. The plus 8-mesh concentrate assayed 40.5 percent iron and the minus 8-mesh product 49.0 percent iron. This gave a combined concentrate assaying 43.7 percent iron and 19.0 percent SiO_2, with a recovery of 71.9 percent.

A subsequent magnetic separation test was run on ore crushed to minus 8-mesh. In this case a recovery of 72.0 percent was obtained in a product that assayed 48.2 percent iron and 17.2 percent SiO_2.

The results obtained by all tests would indicate that coarse-gravity methods of concentration are not applicable to beneficiation of the low-grade Bessemer ores because the magnetite grains are fine and uniformly disseminated in the calcium-magnesium silicate gangue.

If adequate liberation of magnetite is provided by grinding to at least minus 20-mesh, the ore is amenable to treatment by either gravity or magnetic separation methods. The following table indicates the probable grades of concentrates to be obtained by various degrees of crushing or grinding.

Crushing to	*Grade of concentrates* *Fe, percent*	*Recovery, percent*
Minus 2 inches	38.9	65.5
Minus ¼-inch	43.7	71.9
Minus 8-mesh	48.2	72.0
Minus 20-mesh	51.2	70.3

Fine grinding, 48- to 100-mesh, and magnetic separation tests have given 80- to 90-percent recoveries and a plus 60-percent iron product.

SHASTA AND CALIFORNIA DEPOSITS

Magnetite is the principal iron mineral, but limonite and hematite are quite common in the oxidized zone. The gangue minerals consist chiefly of garnet, pyroxene, and epidote. In depth considerable pyrite and minor amounts of chalcopyrite are present.

Lot A, which is typical of the ore that would be mined on a large-scale selective basis, contains gangue inclusions ranging from 20- to 200-mesh in size, and there are also fragments of nearly barren gangue half an inch to 2 inches in size. Tests have shown that recoveries obtained by magnetic separation are approximately the same whether or not reductive roasting is employed. Better sulfur rejection is obtained on unroasted ore. Accordingly, further tests on magnetic separation are confined to unroasted ore.

Analyses of iron ore from Shasta and California deposits

	A	*B*	*C*	*D*	*E*
Fe	40.0	59.4	44.5	37.9	43.6
SiO_2	18.6	6.5	11.84	11.48	11.27
Insol.	35.0	11.0			
S	0.3	0.18	0.094	0.42	0.22
P	0.02	0.02	0.018	0.027	0.005
CaO	10.9	2.70			
MgO	2.3				
Al_2O_3	5.0	3.1			
Mn			0.35	0.27	0.43
Cu		0.02			
Pb		0.05			
Zn		Nil			
TiO_2	0.10	0.05			

A—As main ore body would probably be mined on selective scale.
B—High-grade selected ore.
C—Typical adjusted core and sludge, hole 4 cutoff. 25 percent Fe.
D—Typical adjusted core and sludge, hole 3, cutoff. 25 percent Fe.
E—Channel surface samples.

A sample of minus 2-inch ore was screen sized; the plus ¼-inch fractions were treated by sink-float at a density of 3.28, the plus 20-mesh fractions were jigged and the minus 20-mesh material tabled. The combined gravity concentrates represented a recovery of 87.9 percent of the iron and assayed 52.6 percent iron, 11.4 percent SiO_2, and 0.22 percent sulfur. A representative sample of the combined gravity concentrates was crushed to ¼-inch, mixed with 4 percent by weight of coke, and sintered. Sulfur was effectively removed, and the sinter assayed 53.8 percent iron, 17.8 percent insoluble, 11.4 percent SiO_2, 6.8 percent CaO, 0.03 percent sulfur, and less than 0.01 percent phosphorus.

Wet magnetic separation tests in a Davis tube separator were made on separate samples of unroasted ore ground to minus 8-mesh, 28-mesh, 100-mesh, and 200-mesh, respectively. Treatment of the minus 8-mesh portion showed 89.4 percent recovery of the iron in a magnetic product assaying 59.25 percent iron, 14.3 percent insoluble, 0.01 percent phosphorus, and 0.21 percent sulfur. Three-quarters of the insoluble and over 60 percent of the sulfur and phosphorus were rejected in the nonmagnetic fraction. However, finer grinding was necessary to reduce the sulfur content of the magnetic fraction below 0.10 percent. The test made on minus 100-mesh ore gave a magnetic fraction assaying 67.65 percent iron, 4.4 percent insoluble, 0.01 percent phosphorus, and 0.07 percent sulfur, and an iron recovery of 88.4 percent. Slightly lower sulfur and insoluble assays were obtained on the 200-mesh test, while those on the 28-mesh test were higher.

MINARETS DEPOSITS

Selective mining could be used to obtain a higher-grade product from a mining operation than that indicated by the analyses of A and B.

Magnetite is the chief iron mineral and the gangue consists of actinolite, chlorite, feldspar and epidote.

A head sample split from the lot of ore submitted to the Salt Lake office was assayed with the following result:

Chemical analysis, percent

Fe	*S*	*P*	*LOI*	*Fe^{++}*	*Fe^{+++}*	*MgO*	*SiO_2*	*Insol.*	*CaO*	*Al_2O_3*
33.5	0.01	1.29	+0.74	10.9	22.6	6.0	23.7	41.2	7.8	6.1

The ore consists of fine-grained magnetite in a siliceous gangue. Magnetite grains range from 20- to 800-mesh in size. There are areas of approximately 35-mesh to 48-mesh gangue that are fairly free of magnetite. This might make possible partial concentration at these sizes. To obtain more complete liberation of magnetite, grinding to extremely fine sizes will be necessary, as a large part of the magnetite is present as small, scattered inclusions in the gangue.

The gangue consists of hornblende and diopside. Phosphate is present in the mineral podolite, which is present in grains 20-mesh and smaller and appears to contain fewer inclusions of magnetite than the other gangue minerals.

By jigging the minus 4- plus 10-mesh fraction and tabling the minus-10- plus 20-mesh and the deslimed minus 20-mesh fractions a recovery of 76.6 percent of the iron was made in a concentrate assaying 55 percent iron and 15 percent insoluble. A concentrate assaying 60 percent iron at a recovery of 61 percent of the iron was also made.

Analyses of iron ore from [illegible] deposits

	A	B	C	D
Fe	38.9	21.8	64.19	58.90
Insol.	–	–	–	–
SiO_2	11.72	18.3	2.53	5.98
S	0.007	0.151	0.010	0.008
P	0.51	0.41	0.32	0.38
CaO	5.7	0.9	2.0	4.4
MgO	4.6	4.7	1.6	2.8

A—Ore sections diamond drill hole 1.
B—Ore sections diamond drill hole 2.
C—High-grade massive magnetite, hole 1.
D—High-grade massive magnetite, hole 2.

Magnetic separation proved only moderately successful in beneficiating the ore, principally because much of the magnetite is locked with gangue at plus 20-mesh sizes. However, by treating unsized minus 6-mesh ore a recovery of 72 percent of iron was made in a concentrate assaying 51 percent iron, 20 percent insoluble and 0.62 percent phosphorus. Over 22 percent of the iron concentrated in a middling product assaying 37 percent iron. In addition to indicating incomplete liberation of gangue and magnetite, the results of this test show that the phosphorus content can not be reduced to acceptable limits by treatment of the ore at coarse size. Other tests, as yet incomplete, indicate that grinding to about 48-mesh will be required to obtain liberation of the phosphorus-bearing mineral.

PILOT-PLANT STUDIES

A pilot plant is in course of erection at Shasta Dam, Shasta County, to demonstrate the feasibility of producing special electric furnace steels from California raw materials. The initial plant will include an electric furnace capable of melting and casting 4 tons of steel per melt. This steel will be fabricated at several commercial points on the West Coast in order to obtain data as to its marketability.

One thousand tons of ore from Shasta County has been reduced to sponge iron in the Bureau plant at Laramie, Wyoming. Three hundred tons of California manganese ore has been converted into electrolytic manganese and chrome ore reduced to electrolytic chromium at the Boulder City electrolytic plant. These products will be used in the plant at Shasta Dam for conversion into special-quality alloyed steels.

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
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PART P

Titaniferous Iron-Ore Deposits of the Western San Gabriel Mountains, Los Angeles County, California

By Gordon B. Oakeshott

Issued by the
STATE DIVISION OF MINES

TITANIFEROUS IRON-ORE DEPOSITS OF THE WESTERN SAN GABRIEL MOUNTAINS, LOS ANGELES COUNTY, CALIFORNIA

By Gordon B. Oakeshott*

OUTLINE OF REPORT

ABSTRACT

Numerous titaniferous magnetite bodies of different sizes and shapes occur in gabbro and in anorthosite of the western San Gabriel Mountains, which are located about 25 miles north of Los Angeles. These deposits represent the largest known reserves of titanium in California. No ore bodies in place are being exploited at the present time, but the placer black-sand deposits of the recent streams which are filled with debris from the weathered rocks of the region have recently been mined. At one such locality a concentrate high in ilmenite is being sold for roofing granules, and a magnetite concentrate is finding a market for weight in rollers. Paint companies have shown interest in the ilmenite concentrate as a source of titanium oxide. Separation of ilmenite and magnetite is being made by electromagnets after screening the natural sands to minus 40 mesh. Investigations by the United States Bureau of Mines show that the titaniferous magnetite ores of this region contain a small percentage of vanadium which has not yet been exploited.

The titaniferous magnetite deposits, together with their associated rock formations, were mapped in detail for this report, on 6-minute quadrangles (scale 1 : 24,000) of the United States Geological Survey, namely the Acton, Little Tujunga, Lang, Trail Canyon, Mount Gleason, and Alder Creek quadrangles. In all, 36 deposits are mapped and described. The ore in single deposits ranges in amount from a few tons to more than a million tons, and in grade from about 3 to 25 percent TiO_2; in the best ore body there is an estimated reserve of 250,000 tons of ore carrying 11 to 24 percent TiO_2. The deposits are often not well-defined veins or ore bodies, but represent part of the igneous rock itself, concentrated by late magmatic replacement and injection of the anorthosite-gabbro. Some gold-bearing quartz veins, in places carrying copper sulphides, occur in anorthosite and older rocks but are genetically related to the granodiorite. United States Bureau of Mines assays show traces of silver and as much as 0.01 ounces of gold in the black sands.

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The geologic formations of the western San Gabriel Mountains consist largely of pre-Tertiary plutonic rocks—granodiorite, granite, diorite, monzonite, gabbro, and anorthosite. Included in these intrusive rocks are smaller fragmental bodies of older crystalline rocks. The later igneous bodies are genetically related to one another as comagmatic differentiates of the San Gabriel pluton.

The high-grade ore consists essentially of an intergrowth of ilmenite and magnetite, in varying proportions, and more or less chloritized, actinolitized, and serpentinized pyroxene, with apatite often an important accessory. The ilmenite-magnetite intergrowth probably was formed in a late stage of igneous activity by deep-seated deuteric replacement of earlier minerals, normally crystallized as the magmatic (orthotectic) rock-forming minerals. These reactions of the magma took place essentially before the hydrothermal stage, in which hot-water solutions became dominant. The magma which carried titano-magnetite in solution was most closely related to the gabbro-anorthosite magma and represented part of that fraction which remained fluid late in the consolidation of anorthosite.

The best possibility for early commercial development appears to be in the placer deposits of Sand and Pacoima Canyons where there are large quantities of easily worked sands carrying over 3 percent TiO_2, with some natural concentrations as high as 30 percent TiO_2. United States Bureau of Mines tests on methods of concentration suggest that fine grinding and electro-magnetic treatment would make the best separation of ilmenite and magnetite.

INTRODUCTION

Geographic Features

Numerous bodies of titaniferous magnetite occur in the western San Gabriel Mountains in association with anorthosite-diorite-gabbro rocks. The San Fernando and Tujunga 15-minute topographic quadrangles (scale 1 : 62,500) of the United States Geological Survey cover the area described, which has been mapped more recently on larger-scale 6-minute quadrangles (1 : 24,000), namely the Humphreys, Lang, Ravenna, Acton, Mount Emma, Sylmar, Little Tujunga, Trail Canyon, Mount Gleason, and Alder Creek, and the northern halves of the Pacoima, Sunland, La Crescenta, Mount Lowe, and Mount Wilson quadrangles.

The San Gabriel Mountains form one of the prominent Transverse Ranges of southern California, extending eastward for approximately 65 miles from Saugus to Cajon Pass and reaching a maximum north-south width of about 20 miles near the central part of the range. Cajon Pass, crossed by the San Andreas fault zone, separates this range from the San Bernardino Mountains to the east. West of Newhall Pass near Saugus, the mountains continue at lower elevations and are known as the Santa Susana Mountains. The western part of the San Gabriel Mountains, where the titaniferous magnetite deposits are located, is bordered on the north by the Santa Clara River, flowing through Soledad Canyon, and on the south by San Fernando Valley, the Verdugo Mountains, and the foothills of the Los Angeles Basin area.

The San Gabriel Mountains constitute an extremely rugged range predominantly in the early mature stage of the erosion cycle, thoroughly dissected into steep narrow canyons and ridges, rising from a few hundred feet above sea level to more than 10,000 feet near the eastern end of the range. The highest peak in the area is Mount Gleason, elevation 6,503 feet. Remnants of a more mature topography, an older stage in the erosion cycle, are found in the gently rounded tops of ridges and "flats" of the higher parts of the range. Periodic uplifts in late Quaternary time have left numerous evidences of rejuvenation, renewing the youthful stage, particularly around the southwestern and northwestern borders of the San Gabriel Mountains.

Object of the Report

The geologic investigation upon which this report is based was made by the author at the request of the Geologic Branch of the State Division of Mines to serve as a contribution to Bulletin 129, *Iron Resources of California.* The object of the report is to show accurately, by detailed maps and descriptions, the location, size, extent, composition, geologic position, and origin of the titaniferous deposits in the San Gabriel Mountains. Accurate descriptions are given of all previously reported localities and as many new localities as could be found. The associated formations are described, and their composition, history, and structure are discussed.

Most of the field mapping was done on the 6-minute topographic quadrangles (scale 1 : 24,000) recently completed by Los Angeles County in cooperation with the United States Geological Survey. Aerial photographs (scale 1 : 18,000) of the Fairchild Aerial Surveys were also employed in the field work. Some of the mapping had previously been done by the author in connection with an earlier report,[1] and more recently in connection with a project of detailed aerial mapping of the San Fernando quadrangle, now in progress for the State Division of Mines. All the known deposits of massive titaniferous magnetite in southern California are located either in the San Fernando quadrangle or in the Tujunga quadrangle adjacent on the east; mapping was required in these two quadrangles to include all rock formations with which the ores are associated.

Previous Work

A complete review of the geologic literature of the San Gabriel Mountains is beyond the scope of this paper; actually, very few papers have dealt with the crystalline rocks, and still fewer have mentioned the titaniferous iron ores. Oldest reference to the occurrence of iron ore in the western San Gabriel Mountains found by the writer is in Bulletin 38 of the California State Mining Bureau.[2] This refers briefly to a magnetic ore mined and smelted at Russ Siding in Soledad Canyon in 1906. The deposit was abandoned because of the refractory nature of the ore. Several other reports of the Division of Mines have referred to occurrences of titaniferous iron ore.[3] Tucker [4] summarized all known localities in Los Angeles County, mentioned occurrences in other parts of the world, and included an article on *The Utilization and Metallurgy of Titanium.* Sampson [5] mentioned titaniferous iron in his report, and the author [6] discussed the crystalline rocks of a portion of the western San Gabriel Mountains in considerable detail, making brief reference to the ilmenite-magnetite.

[1] Oakeshott, Gordon B., Geology and mineral deposits of the western San Gabriel Mountains, Los Angeles County: California Jour. Mines and Geology, vol. 33, pp. 215-249, illus., 1937.

[2] Aubury, Lewis E., The structural and industrial materials of California: California Min. Bur. Bull. 38, p. 297, 1906.

[3] Merrill, F. J. H., Los Angeles County: California Min. Bur. Rept. 15, p. 478, 1919.
Boalich, E. S., Notes on iron ore occurrences in California: California Min. Bur. Rept. 18, pp. 110-111, 1923.
Tucker, W. B., Los Angeles field division—Los Angeles County: California Min. Bur. Rept. 23, pp. 295-313, 1927.
Sampson, R. J., Mineral resources of Los Angeles County: California Jour. Mines and Geology, vol. 33, pp. 196-197, 213, 1937.

[4] Op. cit., pp. 295-313.

[5] Op. cit., pp. 196-197, 213.

[6] Oakeshott, G. B., op. cit., p. 248.

William J. Miller published several papers between 1926 and 1931, dealing with the anorthosite in the western San Gabriel Mountains. His paper[7] on the geology of the region includes the results of his earlier work and is chiefly a study of the crystalline rocks. The report is accompanied by a geologic map, scale approximately 1 : 84,000, on which three occurrences of ''magnetic facies of anorthosite'' are shown (pp. 22-23).

The most significant paper on the titaniferous magnetite is that of Moorhouse.[8] His work was entirely a petrographic study, not accompanied by field investigation, but his conclusions are supported, in the main, by the present study. Dehlinger[9] made a local magnetic survey of lower Sand Canyon, but the results of his work have not been published.

ACKNOWLEDGMENTS

Acknowledgment is made herewith to Dr. Thomas Clements for the use of the laboratory facilities of the Department of Geology, University of Southern California, and for field discussion and criticism of the manuscript. Carl E. S. Strem, Chairman of the Department of Physical Sciences at Compton College, contributed some analyses of the titaniferous ores. The writer is indebted to Dr. N. L. Taliaferro for critical reading of the manuscript and editing of the report, and to Dr. Olaf P. Jenkins for suggesting the problem. The State Division of Mines assisted with field expenses. Courtesies of District Ranger M. W. Durham of the United States Forest Service are much appreciated. Special acknowledgment is made to Spangler Ricker, supervising engineer for the United States Bureau of Mines in California for the cooperation of the Bureau in sampling, analyzing, and conducting a series of beneficiation tests of the placer deposits of Sand and Pacoima Canyons.

UTILIZATION OF TITANIUM

Two factors which have created a considerable demand for titanium are its use in alloys in metallurgy, and the introduction of titanic oxide into white composite pigments for painting, lacquering, and similar arts. The industrial uses of titanium and its compounds, arranged in descending order of importance, are: (1) pigments; (2) alloys in metallurgy; (3) dyes, mordants, bleaching agents, strippers, etc.; (4) refractory materials (glazes, enamels, glasses and bricks); (5) smoke screens and pyrotechnics; (6) incandescent media for lighting purposes (arc lamp electrodes); (7) cement; (8) gem stones, natural and synthetic; (9) abrasives; (10) catalysts; (11) ink; (12) medicinal preparations; (13) nitrogen fixation (fertilizers); (14) phosphorus pentoxide; (15) applications in pure science. To these may be added (1) the use of ilmenite grains as roofing sand, (2) the use of titaniferous magnetite in heavy concrete for ballast or in weights for rollers, and (3) the possible use of the finely ground concentrate in pressed castings by

[7] Miller, William J., Geology of the western San Gabriel Mountains of California: Univ. California, Los Angeles, Pub. in Math. and Physical Sci., vol. 1, pp. 1-114, 1934.

[8] Moorhouse, W. W., Some titaniferous magnetites of the San Gabriel Mountains, Los Angeles County, California: Econ. Geology, vol. 33, pp. 737-748, 1938.

[9] Dehlinger, Peter, A magnetic survey of Sand Canyon for placer deposits, San Gabriel Mountains, California: California Inst. Technology, Div. Geol. Sci., Masters Thesis, unpub., 1943.

foundries. Other uses of titanium are discussed in a recent paper by Otto Herres.[10]

Fine grains of ilmenite are well adapted to use as a thin coating with asphalt roofing. Obvious advantages for that purpose are its high specific gravity, good covering qualities in a very thin layer, and its complete resistance to weathering.

Magnetite has been mined and magnetite sands have been used for the manufacture of heavy concrete for ships' ballast. The suggestion is made that some of the larger and more accessible bodies of titaniferous ore in the western San Gabriel Mountains might be of value for that purpose, as much of the rock averages close to 4.0 specific gravity. The black sands concentrated in large amounts in recent stream valleys offer a similar possibility.

The already wide and increasing uses of titanium make it appear likely that the western San Gabriel deposits will eventually be profitably mined; first the titaniferous stream sands, and later the ore in place. The deposits therefore constitute an important titanium reserve.

HISTORY OF SAN GABRIEL DEVELOPMENT

Most of the domestic production of titanium in the United States comes from Nelson and Amherst Counties, Virginia, where ilmenite occurs in place. Titaniferous ores are also mined in Wyoming, Rhode Island, and Minnesota. Titaniferous sands have been mined on the east Florida coast and on the California coast at Aptos, Santa Cruz County, and Redondo Beach, Los Angeles County. The sands of Travancore, India, have been a source of world-wide importance. Other foreign sources of titanium are Norway, Madagascar, and the province of Quebec, Canada. American sand sources are not now in production as they cannot compete with foreign sands.

The first attempt on record to utilize the titaniferous magnetite ore of the western San Gabriel Mountains was at Russ Siding in Soledad Canyon in 1906 (locality Lang 1). An oil furnace was built within a few feet of the Southern Pacific railroad tracks and the ore was brought from a small, rich ilmenite-magnetite body nearby. Apparently the project was initiated with the idea of using the iron, and without recognition of the high titanium content. It was abandoned when the refractory nature of the ore was recognized. Remains of the operation are still evident.

The largest mining operation, now idle, was in connection with that of the Mineral Increment Company (R. C. McInerny, president, Richmond, California) 2.4 miles in an airline southeast of Lang Station (locality Lang 3), on the ridge between Pole and Bear Canyons. Several irregular ore bodies a few feet across, roughly lenticular, occur with irregular masses of white anorthosite, but the principal country rock is gabbro-diorite. A road was built to the property and the ore was mined in 1927 and carried to a bin in Soledad Canyon for shipment to El Segundo for the manufacture of paint base. The DuPont Company made experiments to separate the titanium from the iron without economic success;[11] analyses of a characteristic bin sample were as

[10] Herres, Otto, Titanium—a growing industry: Mining and Metallurgy, vol. 27, no. 472, pp. 210-212, April 1946.
[11] Unpublished report by Spangler Ricker, U. S. Bureau of Mines.

follows: Fe, 46.10; TiO_2, 19.6; V_2O_5, 0.53; P, 0.38; S, 0.026; and SiO_2, 5.23. The presence of more than 0.5 percent vanadium is of considerable interest, as vanadium has not heretofore been reported from these ores. In analyses of ilmenite and apatite, both of which are present, a V_2O_5 content amounting to a few hundredths of one percent is not unusual; but the amount here reported suggests the possibility that the titaniferous ores at the other San Gabriel localities may carry sufficient vanadium to be of commercial value. It is clear that a considerable amount of ore was mined at locality Lang 3, as several adits were driven into the mountain slope, one at least 300 feet long, and abandoned equipment includes a small crusher, engine, several houses, a large ore bin, and 100 feet of track.

Numerous evidences of prospecting activity in connection with the titaniferous deposits were found by the writer, and supported by oral reports from miners and prospectors of the region. Nearly all localities have been filed upon, but many claims have lapsed or changed hands.

The most extensive and systematic prospecting has been done by E. I. DuPont Company, reportedly beginning in 1927 and continuing until 1938. Since that year the company is said to have abandoned all but 10 claims. The company did a considerable amount of work in the Mill Creek area (particularly localities Alder Creek 1, Mount Gleason 7, and Alder Creek 5), at one time employing 18 men to prospect and locate claims. The field work included marking of claims, brushing out claim boundaries, some trenching and sampling, and magnetometer surveys. The Krebs Pigment Division of DuPont conducted the work, with George H. Anderson of the California Institute of Technology in charge. A projected diamond-drilling campaign for the spring of 1938 was not carried out. The company is said to have dropped its interest because of more immediately attractive deposits elsewhere in the United States.

The only operation being carried on at present is at the Live Oak mine in lower Sand Canyon, where sands from the creek bed are being screened and electromagnetic concentrations of ilmenite and magnetite are being made. An account of this operation, begun in 1944, is given in the section below entitled *Placer Deposits*.

SUMMARY OF THE GEOLOGY OF THE CRYSTALLINE ROCKS

Rock formations of the western San Gabriel Mountains

TERTIARY AND QUATERNARY

Sedimentary formations, including the Martinez, Vasquez, Mint Canyon, Modelo, Pico, Saugus; and terrace deposits; some middle (?) Miocene basalt and andesite flows, dikes, and sills.

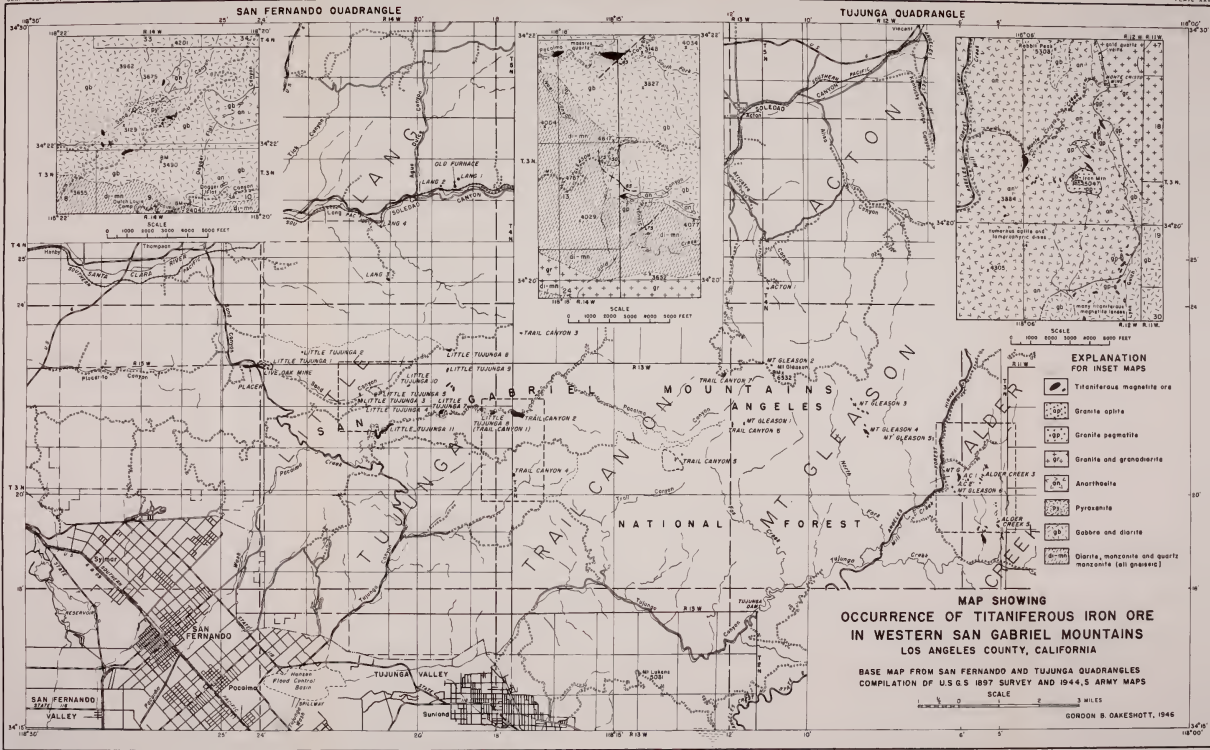
PRE-TERTIARY, UPPER JURASSIC (?)

Granodiorite and associated plutonics, including granite, quartz diorite, and monzonite; aplite, pegmatite, and lamprophyric dikes.
Diorite-monzonite gneiss; gneissic quartz monzonite.
Anorthosite.
Diorite and gabbro.

PRE-TERTIARY, LATE PALEOZOIC (?)

Rubio diorite-gneiss, intruded by granodiorite.
Placerita crystalline limestone and other meta-sedimentary rocks, intruded by Rubio diorite-gneiss and granodiorite.

12 Miller, W. J., op. cit.; Oakeshott, G. B., op. cit.
13 Oakeshott, G. B., A detailed geologic section across the western San Gabriel Mountains of California: Univ. Southern California, Ph.D. thesis, unpub., 1936. . . Geology and mineral deposits of the western San Gabriel Mountains, Los Angeles County: California Jour. Mines and Geology, vol. 33, pp. 215-249, 1937.


SAN FERNANDO QUADRANGLE
TUJUNGA QUADRANGLE
MAP SHOWING
OCCURRENCE OF TITANIFEROUS IRON ORE
IN WESTERN SAN GABRIEL MOUNTAINS
LOS ANGELES COUNTY, CALIFORNIA
BASE MAP FROM SAN FERNANDO AND TUJUNGA QUADRANGLES
COMPILATION OF U.S.G.S 1897 SURVEY AND 1944,5 ARMY MAPS
SCALE
3 MILES
GORDON B. OAKESHOTT, 1946
EXPLANATION
FOR INSET MAPS
Titaniferous magnetite ore
Granite aplite
Granite pegmatite
Granite and granodiorite
Anorthosite
Pyroxenite
Gabbro and diorite
Diorite, monzonite and quartz monzonite (all gneissic)
SCALE
0 1000 2000 3000 4000 5000 FEET
SAN GABRIEL MOUNTAINS
ANGELES NATIONAL FOREST
LITTLE TUJUNGA CANYON
TRAIL CANYON
MT. GLEASON
ACTON
LANG
ALDER CREEK
TUJUNGA VALLEY
SAN FERNANDO VALLEY
SAN FERNANDO
Sylmar
Pacoima
Sunland
OLD FURNACE
LIVE OAK MINE
PLACER
numerous aplite and lamprophyric dikes
many titaniferous magnetite lenses
Mt Lukens 5081

In the central part of the western San Gabriel Mountains there is a relatively large area of pre-Tertiary crystalline rocks, flanked by Tertiary and Quaternary sedimentary formations that show sometimes depositional contacts and sometimes fault contacts, and range in age from Paleocene (Martinez formation) to late Quaternary terrace deposits and alluvium.

Placerita Formation

The oldest formation is the Placerita, a series of metamorphosed sedimentary rocks, occurring mainly as discontinuous, fragmentary outcrops in the extreme southwestern part of the range. Crystalline limestone and dolomite predominate but are often interbedded with quartzites and schists which have been derived from sandstone, pebbly sandstone, and shale. Association of Rubio diorite-gneiss with outcrops of the metasedimentary rocks is exceedingly common, with the diorite intruding the Placerita, often as lit-par-lit injections. Both are intruded by the much later granodiorite. The widely distributed small roof pendants and fragmentary inclusions of the Placerita indicate it was probably once a thick and widespread formation; field study indicates a probable thickness of several thousand feet.

Rubio Diorite-Gneiss

Rubio diorite-gneiss is mostly dark, medium- to coarse-grained gneiss, rich in hornblende; some facies are almost pure hornblendite. In the San Fernando and Tujunga quadrangles occurrence of the diorite-gneiss is very similar to that of the Placerita formation, that is, as relatively small, fragmentary, but widespread inclusions in granodiorite. Often the gneiss is injected lit-par-lit by granodiorite and granite and is also cut by dikes of the granitic rocks. Field evidence is strongly in favor of a much later age for the granodiorite.[12]

The Placerita formation and Rubio diorite-gneiss have been found to always occur in contact with the granodiorite; neither has been found in contact with anorthosite or gabbro. Greater uplift and deeper erosion of the central part of the range have accomplished complete removal of the two older formations there.

Upper Jurassic (?) Intrusives

Exposed in the central and northwestern part of the range is a complex series of closely related intrusive rocks. There are some slight differences in age but evidence previously reviewed [13] and supported by the writer's field work of the past year, shows that the various formations placed as possible Upper Jurassic (?) belong to the same great plutonic invasion. A great variety of plutonic rocks is represented. ranging from titaniferous magnetite ore and pyroxenite to granite pegmatite and aplite. The commonest rock types, named in order of abundance, are granodiorite, diorite, gabbro, anorthosite, monzonite, and granite. For the San Gabriel Range as a whole, granodiorite makes up approximately nine-tenths of the exposed plutonic rock; anorthosite not over 5 percent, and diorite-gabbro, about 5 percent.

[12] Miller, W. J., op. cit.; Oakeshott, G. B., op. cit.

[13] Oakeshott, G. B., A detailed geologic section across the western San Gabriel Mountains of California: Univ. Southern California, Ph.D. thesis, unpub., 1936. . . Geology and mineral deposits of the western San Gabriel Mountains, Los Angeles County: California Jour. Mines and Geology, vol. 33, pp. 215-249, 1937.

Placerita crystalline limestone and other meta-sedimentary rocks, intruded by Rubio diorite-gneiss and granodiorite.

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The feldspar of the anorthosite varies from purplish-gray acid labradorite to white acid andesine and basic oligoclase. Thin-section studies indicate the average feldspar approaches a basic andesine. The rock is rarely foliated but usually minutely fractured. By increase in femic constituents, anorthosite frequently grades into gabbro; along the south border of the anorthosite, particularly, it often shows gradational contacts with gneissic diorite and monzonite; also, at its eastern contact with granodiorite it becomes gneissic, with the banding accentuated by the presence of a higher percentage of femic minerals than the rock mapped as anorthosite usually shows. Near the north and northeast part of the anorthosite mass the rock becomes very white, and some specimens examined microscopically contain sufficient potash feldspar to class the rock as leucomonzonite. This facies apparently grades into medium- to fine-grained pink granite. Parts of the granite are pegmatitic, consisting of large microcline crystals, massive white quartz, and plates of muscovite; graphic intergrowths also occur. Aplite dikes and very irregular aplite intrusions are of frequent occurrence. Along the Indian Creek truck trail of the United States Forest Service and westward in the Ravenna quadrangle, gradation between granite and white anorthosite is so irregular and complex that mapping of the contact between these two rocks is well-nigh impossible.

It is considered that the field relationships of these intrusive rocks, the distribution of the various facies, their primary structural features and petrography, support the following conclusions: (1) The average composition of the San Gabriel Upper Jurassic (?) intrusives is close to quartz diorite; (2) the magmas did not consolidate simultaneously but solidification overlapped during the same general period; (3) the rocks represent comagmatic differentiates of the same batholithic body; (4) the original magma differentiated unevenly and irregularly but largely under gravitational influences, the femic constituents settling and the residual more acidic magmas finally crystallizing as granodiorite around the borders of anorthosite-gabbro; (5) the very latest magmatic activity resulted in development of the pegmatites, aplites, lamprophyric dikes, in various deuteric effects, and in metallization to form titaniferous ore.

No positive evidence has been found as to the age of the complex group of plutonic rocks referred to in this paper as Upper Jurrassic (?), except that they are definitely pre-Tertiary and undoubtedly pre-Cretaceous. The plutonics are older than the Martinez formation (Paleocene) which is exposed in the Little Tujunga and Trail Canyon quadrangles overlying unconformably the crystalline rocks.[14] Previous work by the writer, together with the present investigation, support the conclusion that the granodiorite and related rocks, the gabbro, anorthosite, and pyroxenite, are essentially contemporaneous and genetically closely related, whatever their exact age may be. Granodiorite similar to that of the San Gabriel Mountains is abundant in the nearby Santa Monica and Santa Ana Mountains, where it intrudes fossiliferous Triassic slate[15] and is overlain by Upper Cretaceous conglomerate. In the Santa Monica

[14] Clements, Thomas, and Oakeshott, G. B., Lower Eocene (Martinez) of the San Gabriel Mountains, southern California (abstract): Geol. Soc. America, Proc. 1934, p. 310, 1935.

[15] Mendenhall, W. C., in Willis, Bailey, Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, pp. 505-506, 1912.

Smith, J. P., The middle Triassic marine invertebrate faunas of North America: U. S. Geol. Survey Prof. Paper 83, p. 145, 1914.

Mountains it bears the same relationship to the non-fossiliferous Santa Monica slate (probable correlate of the Triassic Santa Ana slate) and fossiliferous Upper Cretaceous, and is placed by Hoots [16] as "Jurassic(?)". The plutonics are later than the Placerita formation.[17] There is a possibility that the Placerita should be correlated with the Furnace crystalline limestone of the San Bernardino Mountains; fossils from the latter were called Mississippian (?) by Girty.[18]

ORE DEPOSITS

Occurrence

In the attempt to map as many field occurrences of titaniferous magnetite ore and their accompanying rock formations as possible on the 6-minute quadrangles, certain facts concerning occurrence of the ores become increasingly apparent, although their significance as to origin of the ore may permit more than one interpretation. The titaniferous ore always occurs in gabbro or anorthosite. Most of the ore is within 2,000 feet of the anorthosite-gabbro contact, but a few bodies are over a mile from that contact. The ore consists essentially of an ilmenite-magnetite intergrowth, in altered pyroxenite. The augite of the pyroxenite is partly to completely replaced by chlorite, actinolite, and serpentine. The richest ore bodies (rock over half titaniferous magnetite) are found in anorthosite. The ore bodies are irregular in form but are predominantly lenticular. The form and size vary greatly, ranging from small irregular veins to large dike-like lenses; the largest masses are roughly elliptical in plan. In the pyroxenite facies of gabbro the titaniferous magnetite appears irregularly disseminated in the rock. The contacts of the ore with anorthosite and gabbro are as variable as the form and size of the ore bodies. Gradational contacts of titaniferous magnetite-pyroxenite-gabbro-anorthosite are very common, but it is also not uncommon to find very sharp contacts of ore with anorthosite or gabbro. Where several distinct ore bodies occur in close association, they show some orientation with original structural features such as foliation of the anorthosite-gabbro, fracture zones and contacts. The richest ore bodies are found in anorthosite in regions where granite pegmatite, aplite, and lamprophyre dikes are most abundant (Mount Gleason and Alder Creek quadrangles).

Descriptions of Typical Regions

Sand Canyon Area. In upper Sand Canyon and in general, near the western end of the gabbro body, the rock is a heavy, dark, coarse-grained gabbro consisting of labradorite, augite (usually partly or wholly replaced by chlorite and actinolite), apatite, and titaniferous magnetite; olivine is sometimes present. Much of the rock shows gradational changes into pyroxenite or diabasic facies. Medium- to fine-grained pyroxenite also occurs as irregular dikes, apparently intruding gabbro. Lighter more acidic facies of the gabbro occur also, more properly "diorite" rather than gabbro. Most basic facies of the gabbro carry irregularly disseminated grains of titaniferous magnetite, but it is most abundant in the pyroxenite. The areas mapped as ore are those parts

[16] Hoots, H. W., Geology of the eastern part of the Santa Monica Mountains, California: U. S. Geol. Survey Prof. Paper 165, pp. 88-89, 1931.
[17] Miller, W. J., op. cit. Oakeshott, G. B., op. cit. 1937.
[18] Woodford, A. O., and Harriss, T. F., Geology of Blackhawk Canyon, San Bernardino Mountains, California: Univ. California, Dept. Geol. Sci. Bull., vol. 17, pp. 265-304, 1928.

of the pyroxenite in which titaniferous magnetite becomes an appreciable part of the rock, 10 percent or more. The more basic facies of the gabbro and pyroxenite in this region weather to a deep reddish brown in sharp contrast to the lighter dioritic facies and to anorthosite. Small, irregular, discontinuous quartz veins cut all types of rock.

In this region contacts of anorthosite with gabbro are gradational but irregular and abrupt enough to give the appearance, from a short distance, of anorthosite intruding gabbro. Locally, parts of the gabbro, too small to map, become so low in the femic minerals as to merit the name anorthosite. On the map massive gabbro may be seen cutting across gneissic diorite and monzonite. In many places, however, monzonite, diorite, and gabbro show gradational contacts. The diorite-monzonite never carries titaniferous magnetite, and none was found in anorthosite in the Sand Canyon area.

Pacoima-Gold Creek Area. Two irregular, elongated bodies of titaniferous ore of considerable size (localities Little Tujunga 7 and 8) are exposed in Pacoima Canyon. The rock is medium grained, dark, heavy ilmenite-magnetite pyroxenite containing abundant apatite. On the north it grades rapidly through a narrow zone into coarse gabbro. Dark, coarse gabbro is the country rock in the vicinity. Bordering and near both bodies are small, discontinuous quartz veins and masses of uneven outline. One such mass is mapped to the northwest of locality Trail Canyon 2. The quartz always shows sharp intrusive contacts in such occurrences. Many of the quartz veins are iron-oxide stained and some carry scattered sulfides; one such occurrence near elevation 2515 in Pacoima Canyon includes pyrrhotite and siderite.

The gabbro-anorthosite contact is approximately one mile north of Pacoima Canyon. In this area, most of the anorthosite is a very white, medium-grained rock composed largely of andesine; but some consists essentially of plagioclase as acid as basic oligoclase. The contact with gabbro is sharp, the anorthosite appearing to intrude the gabbro. Dikes and tongues of white anorthosite penetrate gabbro. Within the main body of anorthosite there are irregular masses of granite pegmatite up to a thousand feet across, which send forth tongues and dike-like extensions. The pegmatitic rocks are much more resistant to weathering than the white anorthosite, and form minor ridges and knolls. Principal minerals of the pegmatites are massive quartz, microcline, albite, large muscovite crystals, and, more rarely, crystals of green beryl. Quartz forms the greater part of the pegmatite in most places. Pegmatite-anorthosite contacts were observed in a number of places. In some instances they are quite sharp and the pegmatite occurs with definite walls as a dike. In many instances, however, no sharp pegmatite-anorthosite contact could be placed, the granite pegmatite passing imperceptibly into anorthosite.

The small ore body near Slaughter Canyon (locality Trail Canyon 4) is of special interest because it is in contact with so many different rock types. The ore is medium- to fine-grained ilmenite-magnetite pyroxenite (pyroxene chloritized) high in apatite. Alaskite granite and pegmatite occur in sharp contact with pyroxenite, gneissic diorite-monzonite and anorthosite, apparently intruding pyroxenite, gabbro, and diorite-monzonite; whether the pegmatite also intrudes anorthosite is not clear. The alaskite-granite pegmatite carries very small amounts of molybdenite, pyrite, and chalcopyrite. A few thin malachite stains

and much reddish-brown iron oxide have formed from oxidation of the sulfides. Pyroxenite grades into gabbro and anorthosite.

The diorite-monzonite gneiss about a hundred feet south of the pyroxenite is an irregularly banded gneiss made up of light and dark minerals arranged alternately in bands. Specimens of the rock vary within a few feet from quartz monzonite to monzonite, diorite, or gabbro. Some bands are nearly pure, purplish-gray plagioclase, identical with the plagioclase of the anorthosite. Blue quartz and white albitized feldspar are common, forming a rock of very distinctive appearance. As the anorthosite is approached from the south, the anorthosite bands become thicker and more frequent. Banding here does not appear exactly parallel to the gabbro-gneiss contact. The two anorthosite bodies are thick, tabular masses dipping into the steep mountain slope toward the north.

The conflicting evidences of age relationships of the major rock types are the results of mutual boundaries; of overlap in crystallization. The gneiss formed first, and was followed and overlapped by the gabbro, pyroxenite, anorthosite, and pegmatite. Metallization took place late in the series, probably during the time of formation of the pegmatite. No evidence for any age separation of the anorthosite and pegmatite could be found in this locality.

Mill Creek Area. Numerous small to large titaniferous ore bodies are found in the Mill Creek area near the eastern end of the anorthosite body. Most of these are east of the Angeles Forest Highway which follows Mill Creek. Here anorthosite is in contact with granodiorite to the north, east, and south; there is a narrow zone of gneissic gabbro and diorite between anorthosite and granodiorite on the southeast. Especially near the eastern granodiorite contact, the anorthosite is often gneissic. Within a few hundred feet of the eastern and northeastern granodiorite contact, foliation of anorthosite parallels the contact. Gabbro and gabbroic facies of anorthosite are of such frequent occurrence that it was often difficult to decide whether to map the rock as gabbro or anorthosite. Most of the anorthosite is very white plagioclase, but when it grades into the gabbroic facies, the feldspar becomes grayish or purplish.

Aplite and pegmatite are very abundant. Alaskite pegmatite is in irregular masses, sometimes dikes, in both anorthosite and granodiorite. Large parts of the granodiorite east and southeast of Monte Cristo mine are pegmatitic. Most of the pegmatite is composed of quartz, coarse pinkish microcline, albite, some muscovite, and a few small red garnets. The granite aplite occurs in anorthosite as irregular bodies and also as dikes; sometimes as sills in foliated anorthosite. A horizontal dike in anorthosite forms the aplite ring around Iron Mountain. Only in the eastern and northern parts of the anorthosite mass are the aplites and pegmatites very abundant; that is, farthest away from the more basic gabbro and nearest the granodiorite.

At the Monte Cristo mine gold is found in more or less oxidized pyrite in irregular quartz veins. The veins parallel the foliation of dioritic and gabbroic anorthosite, within about 100 feet of the granodiorite contact, but all mineralized veins are definitely in the anorthosite, not in granodiorite.

At the contact, pegmatitic facies of the granodiorite predominate. The Monte Cristo has been the most successful mine in the western San Gabriel Mountains, producing many thousands of dollars worth of gold in the last century. It is now idle.

Basic dikes and dike-like masses a few inches to a few feet across occur throughout the whole anorthosite body, particularly in the Mill Creek area. They are biotite lamprophyres, hornblende lamprophyres, medium- and fine-grained altered pyroxenites, fine-grained diorites, and other fine-grained greenish- and brownish-black rocks so thoroughly altered as to make their naming uncertain. In a great many instances, their age relationships are also uncertain, but some have been observed which are definitely later, and some definitely earlier than pegmatite and aplite. Recognizable lamprophyric dikes were usually more recent than pegmatite where seen in contact. Many of the basic dikes contain noticeable amounts of titaniferous magnetite.

The numerous titaniferous magnetite bodies mapped contain from a few percent to as much as 80 percent ilmenite-magnetite. The balance of the rock always includes an altered pyroxene and very often is high in apatite. Masses of chlorite, actinolite, and antigorite (?) are very common, with unaltered augite often lacking. In the field, dark, greenish, lenticular masses of what appears in the hand specimen as chlorite schist often are high in titaniferous magnetite, although many such masses are barren. The true lamprophyres are low in titaniferous magnetite but such dikes are particularly numerous in the vicinity of the ore bodies.

The frequency with which granite pegmatite is associated with the titaniferous ores is notable. In many places, for example just north of Iron Mountain, pegmatite is found in close association with ilmenite-magnetite and apparently contemporaneous in origin. At locality Alder Creek 4, west of peak 4352, is a lenticular mass of chlorite schist (altered pyroxenite) containing small amounts of ilmenite-magnetite, microcline, and brownish-red garnet. Another similar lens of chlorite schist (without the ilmenite-magnetite and garnet) a few feet west is marked by irregular veinlets of quartz and of coarsely crystalline calcite. The veinlets do not occur in the surrounding anorthosite.

The largest, richest ore body in the Mill Creek area, locality Alder Creek 1, is a roughly lenticular mass consisting of approximately 75 percent ilmenite-magnetite, and 25 percent chloritized pyroxene with a small amount of apatite. It grades through a zone a few feet thick into gabbroic anorthosite and anorthosite.

Summary of Titaniferous Magnetite Localities

The object of this section is to indicate as clearly as possible the localities in which titaniferous magnetite bodies occur and to give a brief description of such occurrences. For convenient reference each locality is first shown by reference to the current edition of the 6-minute quadrangle (available on July 1, 1945); each description is followed by reference to any previous mention of the locality in the literature. An effort has been made to study all occurrences in the field and to make corrections in the locations where inaccuracies have crept into previously published reports.

Lang Quadrangle

Lang 1. Russ siding on Southern Pacific railroad in Soledad Canyon. Ore body 1,000 feet north of tracks up nearby creek, east side, near old houses. Short tunnel in irregular, small mass ilmenite-magnetite in fractured white anorthosite, where ore was mined in 1906. Merrill, F. J. H. 19; Boalich, E. S. 23; Tucker, W. B. 27; Sampson, R. J. 37.

Lang 2. 2,000 feet due west of Russ sign post. Traces of titaniferous magnetite in small masses of dark diorite-gabbro in anorthosite, very near pink granite.

Lang 3 (Titian claims). 2.4 miles southeast of Lang station, near divide between Pole and Bear canyons at end of old road built to mine, very near extreme southeast corner, section 21. Several irregular ore bodies a few feet across, roughly lenticular in outline, occurring with irregular masses of white anorthosite; principal country rock is gabbro-diorite with main gabbro-anorthosite contact 1,800 feet to the northeast. Ore mined in 1927. Ore bodies small and irregular but by no means exhausted. Chemical analysis of a typical specimen of the ore shows 18 percent TiO_2 and 65 percent iron oxides. As far as the writer has been able to determine, this represents the first successful instance of the mining of titaniferous ore in the San Gabriel Mountains. Tucker, W. B. 27; Sampson, R. J. 37; Miller, W. J. 34.

Lang 4. Mouth of Bear Canyon 1.7 miles east and 0.4 miles south of Lang. Titaniferous magnetite in anorthosite at gabbro-anorthosite contact. Miller, W. J. 34.

Acton Quadrangle

Acton 1. Near southwest corner Acton quadrangle on truck trail southwest of Arrastre Canyon 2,800 feet north of boundary of Mount Gleason quadrangle. Small amounts of titaniferous magnetite with quartz, microcline and hornblende in gabbroic anorthosite. There are many small occurrences of the ore in this vicinity, sometimes in association with very large, black crystals of hornblende and green epidote.

Little Tujunga Quadrangle

Little Tujunga 1. Lower Sand Canyon, extending from west boundary Little Tujunga quadrangle for 1,800 feet due east and from Sand Creek 800 feet north. Titaniferous pyroxenite and basic gabbro with varying proportions of ilmenite-magnetite. For account of placer deposits in this part of Sand Canyon, see section below on *Placer deposits*.

Little Tujunga 2 (Needham and Boruff group). Three claims in section 31 in Iron Canyon 4 miles south of Lang. Iron Canyon exposes coarse gabbro, often grading into pyroxenite and with pyroxenite dikes containing titaniferous magnetite. No true ore could be found on these claims. Sampson, R. J. 37, p. 197.

Little Tujunga 3. Upper Sand Canyon, two outcrops on truck trail and one at creek junction 2,000 feet northeast of junction of Sand Canyon truck trail. The rock is gabbro and basic diorite with irregular masses, and also definite dikes, of altered pyroxenite. The pyroxenite is medium to fine grained and contains abundant titaniferous magnetite and apatite.

Little Tujunga 4. On Santa Clara truck trail half a mile northeast of junction of Sand Canyon truck trail and 1,000 feet southeast of locality 3 above. Similar rock association to locality 3.

Little Tujunga 5. Upper Sand Canyon and Santa Clara truck trail in large area of basic gabbro and pyroxenite, about 2,000 feet northeast of localities 3 and 4. The area mapped as "pyroxenite" is largely medium- to fine-grained pyroxenite in which the augite is chloritized and actinolitized, apatite is very abundant and titaniferous magnetite varies in amount. The rock weathers to deep brownish red. An analysis of pyroxenite similar to that of localities 3, 4, and 5 showed 5 percent TiO_2, 6 percent P_2O_5 and 43 percent iron oxides. These are reasonable figures for the ore of these three localities.

Little Tujunga 6. Outcrops on ridge and head of canyon approximately 3,000 feet east of Magic Mountain (elevation 4,878, formerly designated "Iron Mountain"). Scattered small outcrops of titaniferous magnetite in grayish-white anorthosite.

Little Tujunga 7. In Pacoima Canyon 2,400 feet west of junction with Gooseberry Canyon. Medium-grained pyroxenite high in titaniferous magnetite. Pyroxenite is roughly lenticular mass in dark gabbro. Very similar rock to locality 8 below; relatively low in TiO_2.

Little Tujunga 8. In Pacoima Canyon on boundary between Little Tujunga and Trail Canyon quadrangles. Medium- to fine-grained pyroxenite high in titaniferous magnetite and apatite. Associated are massive quartz veins and irregular quartz masses; also some lamprophyric dikes. Analysis of a typical specimen showed 5 percent TiO_2, 6.5 percent P_2O_5 and 44 percent iron oxides.

Little Tujunga 9. Ridge between Rattlesnake and Dorothy Canyons, just southwest of peak 3969. Small amounts of ilmenite-magnetite in pyroxenite.

Little Tujunga 10. Dagger Flat Canyon, in creek at elevation 3200. Similar to 9 above.

Little Tujunga 11. Placer deposits in Pacoima Canyon extending westward from Dagger Flat. See section below on *Placer deposits*.

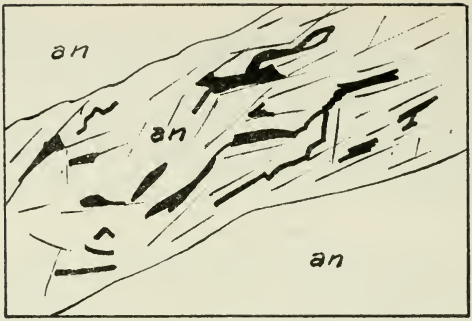

FIGURE 65. Field sketch from canyon-side, locality Mount Gleason 3.

Fractured zone about 5 feet wide in grayish anorthosite. Solid black is titaniferous magnetite with chlorite, actinolite, quartz, apatite, and small scattered grains of pyrite, chalcopyrite and bornite. Much of the plagioclase associated with the ore is surrounded by narrow, green, actinolite reaction rims.

Trail Canyon Quadrangle

Trail Canyon 1. In Pacoima Canyon, eastward continuation of Little Tujunga 8 above.

Trail Canyon 2. In Pacoima Canyon beginning 2,000 feet east of boundary of Little Tujunga quadrangle and extending eastward for 1,200 feet to fault in Pacoima Canyon. The rock in which the ore occurs is an ultra-basic facies of the gabbro, consisting of fine- to medium-grained pyroxenite with augite altered to chlorite and actinolite, abundant ilmenite-magnetite and abundant euhedral apatite. An analysis of one of the more basic facies of the pyroxenite showed 11 percent TiO_2, 5½ percent P_2O_5 and 50 percent iron oxides. Average for this large body is probably 5 percent to 15 percent TiO_2. The ultra-basic rock grades into coarse gabbro to the northeast. Irregular masses and veins of massive quartz occur in the pyroxenite.

Trail Canyon 3. Near northwest corner Trail Canyon quadrangle 200 feet southwest of junction of two truck trails on ridge at head of Bear Canyon. Small outcrops titaniferous magnetite-chlorite rock in anorthosite. Abundant granite pegmatite in this vicinity.

Trail Canyon 4. In branch canyon 800 feet west of upper Slaughter Canyon and 3,000 feet east of boundary of Little Tujunga quadrangle. Outcrops chloritized titaniferous pyroxenite grading into purplish anorthosite-gabbro and in contact with gneissic diorite-gabbro, grayish anorthosite and granite. Pegmatite carries small amounts molybdenite, pyrite, and chalcopyrite. Abandoned shallow prospect tunnel.

Trail Canyon 5. South and southeast slopes Iron Mountain (elevation 5632), particularly 1,800 feet southeast of Iron Mountain on Trail Canyon trail. An area about half a mile wide north and south and one mile long northwest and southeast consists of an ultra-basic facies of gabbro in gabbro and diorite. The rock is mainly altered pyroxenite with many very irregular and discontinuous masses of titaniferous magnetite, usually with abundant chlorite. Trail from elevation 5025 has been widened to make a prospect road connecting with Mount Gleason truck trail half a mile to northeast. No large masses of good ore. Tucker, W. B. 27; Sampson, R. J. 37; Miller, W. J. 34.

Trail Canyon 6. Mount Gleason truck trail 200 feet west of east boundary of Trail Canyon quadrangle. Ultra-basic dike-like body a few feet thick in dark diorite-gabbro. Small percentage of titaniferous magnetite in dike.

Trail Canyon 7. On ridge, elevation 5525, between loops of Modie Canyon truck trail, 1,000 feet west of boundary of Mount Gleason quadrangle and 8,400 feet south of boundary of Ravenna quadrangle. Massive titaniferous magnetite, with chlorite, and smaller amounts of quartz and microcline; country rock is anorthosite.

Mount Gleason Quadrangle

Mount Gleason 1. Mount Gleason truck trail 1,500 feet east of boundary of Trail Canyon quadrangle. Small outcrops titaniferous magnetite in gabbro. Miller, W. J. 34.

Mount Gleason 2. Trail 1,800 feet northwest of Mount Gleason. Outcrop titaniferous magnetite in gabbro. Miller, W. J. 34.

Mount Gleason 3. North-central part of quadrangle. Beginning at a point 400 feet south of elevation 5326 and 4,000 feet south of Mount Gleason truck trail and continuing from this point for about 1,600 feet in a west-northwest direction, thence north-northwest for about 1,500 feet to power line truck trail, numerous very irregular, small outcrops titaniferous magnetite occur. Commonly appears in a zone a few feet wide, interrupted and broken, including chlorite, quartz and grayish anorthosite, with plagioclase crystals often bordered by green, fibrous reaction rims. Pegmatitic and lamprophyric dikes common.

Mount Gleason 4. On ridge slopes about 300 feet northwest of peak 5147 and half a mile southeast of locality 3 above. Lenticular dike-like mass of titaniferous magnetite, with chlorite, plagioclase, and quartz, irregularly striking northwest for about 600 feet. Very small outcrop magnetite on peak. Country rock is grayish anorthosite; little or no aplite in this vicinity. Miller, W. J. 34.

Numerous similar small occurrences of titaniferous magnetite in the general vicinity of localities 3 and 4.

Mount Gleason 5. 400 feet west of Angeles Forest Highway and 4,000 feet north of Monte Cristo Creek road. Ilmenite-magnetite in pyroxenite in numerous small outcrops on west side of Mill Creek; country rock is gray anorthosite. Many dikes and irregular masses of aplite and granite pegmatite. Tucker, W. B. 27; Sampson, R. J. 37.

Mount Gleason 6. About 2,000 feet east of Angeles Forest Highway and Mill Creek and 4,000 feet south of Monte Cristo Creek road. South and east of peak 3864 are several small masses titaniferous magnetite in anorthosite; numerous aplite and lamprophyre dikes. Tucker, W. B. 27; Sampson, R. J. 37.

Mount Gleason 7. On boundary between Mount Gleason and Alder Creek quadrangles and extending from Monte Cristo Creek south for 1,000 feet to saddle. Important ore body. See locality Alder Creek 1. Tucker, W. B. 27; Sampson, R. J. 37; Miller, W. J. 34.

Alder Creek Quadrangle

Alder Creek 1. On boundary between Mount Gleason and Alder Creek quadrangles and extending as a lenticular mass for 1,000 feet south of Monte Cristo Creek to a saddle in ridge. Maximum width about 200 feet. Massive, almost solid titaniferous magnetite with chlorite and hornblende; quite sharp contacts with surrounding grayish anorthosite. Chemical analysis of a typical specimen shows 18 percent TiO_2, 0.26 percent P_2O_5 and 63 percent iron oxides. The deposit is the most accessible and the largest body of very high-grade ore that the writer has examined. Tucker, W. B. 27; Sampson, R. J. 37; Miller, W. J. 34.

Alder Creek 2. Numerous small outcrops titaniferous magnetite in gray anorthosite irregularly distributed along ridge for about 3,000 feet from Iron Mountain (elevation 5047, also known as "Little Iron Mountain") westward to locality 1 above.

Alder Creek 3. On Iron Mountain (elevation 5047) and north-northeast along ridge for 3,300 feet are found numerous small lenses and dike-like masses of ilmenite-magnetite associated with abundant green chlorite. Numerous lamprophyre dikes with low percentage titaniferous magnetite; aplite and abundant granite pegmatite a few feet across in gabbroic anorthosite, surrounded by ring of aplite 1,200 to 1,800 feet in diameter; aplite is evidently a horizontal dike approximately 200 feet thick. Tucker, W. B. 27; Sampson, R. J. 37.

Alder Creek 4. Peak at elevation 4550 + (600 feet east of boundary of Mount Gleason quadrangle and 4,000 feet southwest of Iron Mountain), and just west of peak. Small amounts of titaniferous magnetite in chlorite schist (from chloritized pyroxenite) with microcline, brownish-red garnet, quartz veinlets and calcite veinlets.

Alder Creek 5. From Lynx Gulch to next intermittent stream west (unnamed) and from few hundred feet north of Big Tujunga Canyon occur hundreds of large and small irregular masses and dikes of titaniferous-magnetite-rich chlorite schist and pyroxenite, sometimes with sharp contacts against anorthosite and gabbro, and sometimes grading into coarse basic gabbro which also carries titaniferous magnetite. Lamprophyre dikes, aplite, and granite pegmatite are numerous.

FIGURE 66. Sketch from thin section of actinolitized titano-magnetite pyroxenite, plane polarized light, mag. 60X.

Pale, gray-green to yellow, pleochroic, hornblende (H) (actinolite), penetrated and embayed by ilmenite-magnetite; some of the magnetite has crystallized in hornblende cleavage cracks. Ilmenite-magnetite is also later than epidote (E), clinozoisite (Clz), and chlorite (Cl). CA is a complex fibrous aggregate of chlorite and antigorite (?) which appears to replace green hornblende.

FIGURE 67. Sketched from thin section of gabbro (?), plane polarized light, mag. 90X.

Ilmenite-magnetite penetrating and embaying abundant large crystals of apatite (A), biotite (B), chlorite (Cl), and actinolite (H). BC is a clouded mass of alteration and replacement minerals, including chlorite, calcite, quartz, albite, and sericite, totally replacing plagioclase. Note especially lower center, where ilmenite-magnetite has penetrated and crossed a single apatite crystal and has replaced bordering minerals along their contacts.

FIGURE 68. Sketched from polished surface of titaniferous magnetite, etched by HCl, reflected light, mag. 40X.

Lattice-work intergrowth of ilmenite (light) in magnetite. In this section ilmenite is developed parallel to crystal directions in magnetite, but in some sections as ilmenite becomes more abundant it appears as large, irregular patches.

This is one area in which it is reported that the E. I. DuPont Co. carried on magnetometer surveys and "intended to begin diamond drilling in the spring of 1938" (Sampson, R. J. 37, p. 213). The writer found these deposits to be very discontinuous, widely scattered, usually low-grade and not very accessible. DuPont apparently dropped its interests in this region and did not carry through the diamond drilling campaign as intended.[19]

Placer Deposits

Sand Canyon (Little Tujunga Locality 1). Live Oak mine,[20] 800 feet east of the west boundary of Little Tujunga quadrangle in Sand Canyon, is now operating an electromagnetic mill using sands in the creek bed extending from the mill location for over 2,500 feet downstream due west. Bedrock exposed in the drainage area of Sand Canyon is essentially coarse gabbro rich in the pyroxenite facies which carries varying percentages of ilmenite-magnetite. The coarse gabbro itself is frequently 5 percent or more titaniferous magnetite. The more nearly pure ilmenite-magnetite rock is very resistant to weathering, but the coarse gabbro low in ilmenite-magnetite is often thoroughly weathered to a reddish-brown sand. It is the latter which stream action has concentrated to form the titaniferous sands in the stream alluvium. A tunnel has been run into the large mass of ilmenite-magnetite pyroxenite on the north side of the canyon at the mill-site but this ore in place is not now used as the product after mining and crushing is lower in TiO_2 than the natural stream concentrate. Large amounts of sand are available as Sand Canyon widens rapidly west of the mill.

Pacoima Canyon (Little Tujunga Locality 11). Pacoima Creek alluvium from Dagger Flat downstream for more than 4,000 feet carries notable amounts of black sand. Extensive sampling of the sands by the United States Bureau of Mines shows as high as 30.8 percent TiO_2, the lowest, 2.4 percent TiO_2. United States Forest Service pits indicate the alluvium is commonly more than 40 feet deep. Ilmenite-magnetite in the sands has been concentrated by stream action and derived directly from the weathering of titaniferous magnetite gabbro, which is abundant in the gabbroic rocks in the Pacoima drainage area above Dagger Flat. A United States Bureau of Mines analysis of gabbro typical of the source rock at the west end of Dagger Flat shows 5.4 percent TiO_2. Reserves of easily worked sand are as large or larger than at the Live Oak mine, and field examination indicates the Pacoima concentrations may be better.

Analyses and Concentration Tests. An investigation of the Pacoima and Sand Canyon placers was made by the U. S. Bureau of Mines in cooperation with the State Division of Mines in order to obtain an idea of the tonnage and the mineral content of the sands and to make beneficiation tests on representative samples. The investigation was initiated and a report prepared by Spangler Ricker, Supervising Engineer for the State of California, U. S. Bureau of Mines. A. C. Rice and staff, of the Reno Rare and Precious Metals Experiment Station, were responsible for the tests and analytical work. C. L. Severy, engineer of the Bureau of Mines, Dr. Olaf P. Jenkins, then Chief Geologist of the California State Division of Mines, and the writer made a field investigation and collected 800 pounds of samples on November 10, 1945. Twelve samples, weighing 75 to 100 pounds each, were taken from various places. Six were from placer ground in Pacoima Canyon downstream from Dagger Flat, four were from the Live Oak mill and Sand Canyon placer, and two were of rock in place.

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[19] Oral communication from miners in the region.
[20] Operated by Challoner Thompson, Sand Canyon, Route 1, Saugus, California.

Analyses of titaniferous sand samples

U. S. B. M. sample No.	Percent Fe	Percent TiO_2	Percent V_2O_5	Au	Ag	Description
73	32.80	8.9	0.04	0.0025	Tr	Massive ore in gabbro from Pacoima Canyon, 2,000 feet east of Dorothy Canyon.
78	23.11	5.4	0.01	0.0025	Tr	Weathered gabbro, typical of source of sands, Pacoima Canyon, west end Dagger Flat.
74	17.91	11.61		Tr	Tr	Fine sand from wash, Pacoima Canyon, 2½ feet thick at tunnel location. SE¼ sec. 9.
75	18.96	14.92	0.0123	Tr	Tr	2-foot section sand, 200 feet upstream from sample 74.
76	7.36	3.47	0.0095	0.001	Tr	Typical material between boulders, 200 feet upstream from 75.
77	33.00	30.8	0.05	Tr	Tr	Typical stream concentrate, Pacoima Canyon, 350 feet east of upstream tunnel entrance, 2 feet thick.
79	9.48	3.29	0.002	0.0025	Tr	Dump, Forest Service pit, center Pacoima Canyon, lower end Dagger Flat.
80	8.41	2.41		0.0025	Tr	5-foot sample, sand and gravel bank, 50 feet north of 79.
81	50.80	9.8	0.18	Tr	Tr	Magnetite concentrates, Live Oak mill, Sand Canyon.
82	33.52	31.3	0.03	Tr	Tr	Ilmenite concentrates, Live Oak mill, Sand Canyon.
83	12.40	7.6	0.01	Tr	Tr	Rejects from Live Oak mill
84	16.73	7.49		Tr	Tr	Typical sand feed for Live Oak mill, 200 yards below bridge, Sand Canyon.

Spectrographic examination of Dore bead obtained by fusion and cupellation failed to detect platinum and examination of the original material failed to detect the presence of columbium, tantalum, thorium, or any of the rare earth elements.

Gravity concentration tests were made on seven of the samples (74, 75, 76, 79, 80, 84, 78) but the results were unsatisfactory, indicating that it would not be possible to make a high-grade concentrate by gravity alone. Retabling the concentrate did no good.

A test was made of 10 grams of concentrates to determine what could be done by magnetic separation, with the following results:

Product	*Percent of weight*	*Percent Fe*	*Percent TiO_2*	*Percent of total distribution Fe*	*TiO_2*
Magnetic	35	54.46	8.7	53.0	17.8
Non-magnetic	65	25.96	21.7	47.0	82.2

Although there is a considerable concentration of titanium in the non-magnetic portion, it is clear that simple magnetic treatment will not accomplish a good separation. In the magnetic portion, 94 percent of the iron was found to be acid soluble, whereas only 46 percent of the iron in the non-magnetic portion was acid soluble. The insoluble iron is, no doubt, the iron contained in the ilmenite. The results of this test are as would be expected from the fact that the titaniferous magnetite is an intergrowth of ilmenite and magnetite of medium to very fine microscopic texture.

A final magnetic test was made on some retabled gravity concentrate in which three products were obtained by use of the magnet (strongly magnetic, slightly magnetic, and non-magnetic) with the following results:

Product	*Percent of weight*	*Percent Fe*	*Percent TiO_2*	*Distribution Percent Fe*	*TiO_2*
Strongly magnetic	14.2	38.54	10.2	29.0	6.9
Slightly magnetic	11.7	21.96	32.6	13.5	18.0
Non-magnetic	66.8	14.36	23.3	50.6	73.2
Tails	7.3	17.90	5.6	6.9	1.9

Results of the test show that a somewhat higher-grade product can be made by elimination of the strongly magnetic material and suggest that better results might be obtained by closer sizing and by using variable intensity magnets.

At the Live Oak mine natural sand averaging about 7½ percent TiO_2 is being screened to minus 40 and run over electromagnets of various intensity selected after considerable experimentation by the operator. This treatment is resulting in an ilmenite concentrate containing 59.3 percent ilmenite (assuming all TiO_2 to be in the mineral ilmenite) and 16.2 percent magnetite, while the magnetite concentrate being obtained is 61.00 percent magnetite and 18.46 percent ilmenite. The high-grade natural stream concentrates are very close to the ilmenite concentrate from the mill, the stream concentrates containing 58.3 percent ilmenite and 15.8 percent magnetite.

Origin

The titaniferous ore has been formed by very late igneous processes in connection with the intrusion of gabbro and anorthosite. An ilmenite-magnetite intergrowth commonly makes up a few percent of the more basic facies of the gabbro, the intergrowth partially replacing the original magmatic (orthotectic) minerals of the rock and occurring late in the series of late-magmatic (deuteric) minerals. The process of late-magmatic replacement to form titaniferous magnetite began before final consolidation of gabbro and anorthosite and continued after the anorthosite had consolidated sufficiently to fracture. Titaniferous magnetite is most abundant in a pyroxenite facies of the gabbro-anorthosite. Many of the ore bodies are poorly defined, irregular masses of titanomagnetite pyroxenite and gabbro grading into normal gabbro or anorthosite.

Evidence of the emplacement of the *larger* bodies of ore in zones of fracture or faulting is uncertain or lacking. On the contrary, wherever clear-cut contacts of large ore bodies with anorthosite were observed they appeared gradational, although often gradational through a zone of a few feet only. Pyroxenite ore bodies in basic gabbro show convincing evidence of gradation not influenced by fracturing or faulting. It is probable that much of the ore-rock was emplaced during final consolidation of anorthosite-gabbro and that injection of magmatic solutions to form ore-rock continued after consolidation of at least part of the anorthosite. The anorthosite-gabbro is not strongly foliated as a whole, but in many places it is locally foliated. Numerous instances of the local concentration of ore veinlets in small fractures in anorthosite are found in the field. There can be no question that at least some of the ore solutions were injected into anorthosite already cool enough to fracture. In such regions there is also a more or less general parallelism of elongated ore bodies which is suggestive of orientation with the contact and with anorthosite-gabbro foliation. Gold-bearing and sulfide-bearing quartz veins, generally later than the titaniferous ore, show a very definite orientation to foliation of anorthosite-gabbro.

A close relationship between the deuterically-altered titanomagnetite pyroxenites and the pegmatites is demonstrated by both field and laboratory evidence. It is notable that their development took place during the same stage of igneous activity, that the highest frequency of rich titaniferous ore bodies is in regions of highest frequency of granite pegmatites in anorthosite, that there is a common occurrence of pegma-

titic minerals and textures in the same rock specimens with titano-magnetite, augite, chlorite and actinolite, and that similar forms of ore-rock bodies and pegmatite bodies are found, both appearing as dikes, as vein-like injections, and as lenticular bodies.

ESTIMATE OF ORE RESERVES

An estimate of the reserve of titaniferous ore at each locality follows. The grade of ore indicated is based on the analysis of a typical sample or analysis of similar ore from a nearby locality. The tonnage in reserve is based on field mapping and the assumption that the ore body is half as deep as the horizontal width of its outcrop, known to be a reasonable assumption in most cases. The reader should understand the limitations on accuracy of such estimates, but an effort has been made to keep them conservative and yet to give some indications of probable amounts of ore.

Locality	*Estimated tonnage of available ore*	*Estimated percentage of TiO_2*
Lang 1	100	18–20
Lang 2	No ore	-----
Lang 3	200,000 in scattered ore bodies	18–20
Lang 4	No ore	-----
Acton 1	2,000 in scattered small bodies	5–10
Little Tujunga 1	200,000 in place; for est. of placer see below	8
Little Tujunga 2	No ore	-----
Little Tujunga 3	100,000 in scattered bodies	5–10
Little Tujunga 4	70,000	5– 8
Little Tujunga 5	80,000	5– 8
	and several hundred thousand	3– 5
Little Tujunga 6	50,000 in scattered small bodies	5
Little Tujunga 7	750,000 in single body	5– 6
Little Tujunga 8	800,000 in single body	5– 6
Little Tujunga 9	10,000 in scattered bodies	4– 5
Little Tujunga 10	5,000 in scattered bodies	4– 5
Little Tujunga 11	For estimate of this placer see below	-----
Trail Canyon 1	Included in Little Tujunga 8 above	-----
Trail Canyon 2	6,000,000 in single large ore body	5–15
Trail Canyon 3	5,000	5
Trail Canyon 4	300,000	5
Trail Canyon 5	Several million tons 2–3%; few thousand tons 5–15%	2–15
Trail Canyon 6	100,000 in dike-like body	10
Trail Canyon 7	300,000	5
Mt. Gleason 1	10,000	5–10
Mt. Gleason 2	Few thousand	5–10
Mt. Gleason 3	Scattered bodies in fracture zone; little ore	-----
Mt. Gleason 4	180,000	5–10
Mt. Gleason 5	Many small outcrops; little ore	-----
Mt. Gleason 6	Many small outcrops; little ore	-----
Mt. Gleason 7	250,000 in single body	11–25
Alder Creek 1	Same ore body as Mt. Gleason 7	-----
Alder Creek 2	Numerous small bodies; little ore	-----
Alder Creek 3	Numerous small bodies; little ore	-----
Alder Creek 4	Few small bodies; little ore	-----
Alder Creek 5	2,000,000 in hundreds of separate ore bodies, often small	3–20

An accurate estimate of the tonnage of workable sands in the Sand Canyon and Pacoima Canyon placers is impossible, as no complete sampling by bore holes has been made. At the Live Oak mine in Sand Canyon a shaft sunk 40 feet in alluvium in a narrow part of the canyon

had not yet encountered bed rock. Samples from the shaft show highly variable percentages of titanium up to lenses of sand as high as 30 percent TiO_2. The valley widens below the mine and titaniferous sands extend for more than half a mile. There is little question that several million tons of profitable sand are readily accessible. The Live Oak mine has not made a complete sampling as the quantity of sand in sight insures operation at their present capacity for a considerable time.

The Pacoima Canyon titaniferous sands have not been worked but are equally promising. The best surface sand appears in the part of the canyon extending downstream from Dagger Flat for one mile. Several holes dug in the alluvium by the U. S. Forest Service indicate the sands and gravels average 30 to 50 feet deep, even in parts of the canyon as narrow as 200 feet. United States Bureau of Mines samples indicate the poorest gravels carry 2.4 percent TiO_2 and the richest natural sand concentrates as much as 30.8 percent TiO_2. As in Sand Canyon, several million tons of workable sand is available, but the Pacoima locality is much less accessible to transportation.

BIBLIOGRAPHY

Alling, Harold L.
36 Interpretative petrology of the igneous rocks, 353 pp., 1936.

Aubury, Lewis E.
06 The structural and industrial materials of California: California Min. Bur. Bull. 38, p. 297, 1906.

Boalich, E. S.
23 Notes on iron ore occurrences in California: California Min. Bur. Rept. 18, pp. 110-113, 1923.

Buddington, A. F.
39 Adirondack igneous rocks and their metamorphism: Geol. Soc. America Mem. 7, 354 pp., 1939.

Clements, Thomas
35 (and **Oakeshott, G. B.**) Lower Eocene (Martinez) of the San Gabriel Mountains, southern California (abstract): Geol. Soc. America Bull., vol. 46, p. 310, 1935.

Dehlinger, Peter
43 A magnetic survey of Sand Canyon for placer deposits, San Gabriel Mountains, California: California Inst. Technology, Div. Geol. Sci., Master's Thesis, unpub., 1943.

Gillson, Joseph L.
32 Genesis of the ilmenite deposits of St. Urbain, County Charlevoix, Quebec: Econ. Geology, vol. 27, pp. 554-577, 1932.

Herres, Otto
46 Titanium—a growing industry: Mining and Metallurgy, vol. 27, no. 472, pp. 210-212, April 1946.

Hoots, Harold W.
31 Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, California: U. S. Geol. Survey Prof. Paper 165, pp. 83-134, 1931.

Merrill, F. J. H.
19 Los Angeles County: California Min. Bur. Rept. 15, pp. 465-514, 1919.

Miller, William J.
34 Geology of the western San Gabriel Mountains of California: Univ. California, Los Angeles, Pub. Math. and Phys. Sci., vol. 1, pp. 1-114, 1934.
45 Observations on pseudo-dikes and foliated dikes: Jour. Geology, vol. 53, pp. 175-190, 1945.

Moore, Charles H., Jr.
40 Origin of the nelsonite dikes of Amherst County, Virginia: Econ. Geology, vol. 35, pp. 629-645, 1940.

Moorhouse, W. W.
38 Some titaniferous magnetites of the San Gabriel Mountains, Los Angeles County, California: Econ. Geology, vol. 33, pp. 737-748, 1938.

Oakeshott, Gordon B.
36 A detailed geologic section across the western San Gabriel Mountains of California: Univ. Southern California, Ph. D. Thesis, unpub., 1936.
37 Geology and mineral deposits of the western San Gabriel Mountains, Los Angeles County: California Div. Mines, Rept. 33, pp. 215-249, 1937.

Osborne, F. F.
28 Certain magmatic titaniferous iron ores and their origin: Econ. Geology, vol. 23, pp. 724-761, 895-922, 1928.

Ross, C. S.
33 Titanium deposits of the Roseland district: Internat. Geol. Cong. Guidebook 11, Northern Virginia, 1933.
36 Mineralization of the Virginia titanium deposits: Am. Mineralogist, vol. 21, 1936.
41 Occurrence and origin of the titanium deposits of Nelson and Amherst Counties, Virginia: U. S. Geol. Survey Prof. Paper 198, pp. 1-38, 19 pl., 1941.

Ryan, C. W.
33 The ilmenite apatite deposits of west central Virginia: Econ. Geology, vol. 28, pp. 266-275, 1933.

Sampson, R. J.
37 Mineral resources of Los Angeles County: California Jour. Mines and Geology, vol. 33, pp. 173-213, 1937.

Smith, James Perrin
14 The middle Triassic marine invertebrate fauna of North America: U. S. Geol. Survey Prof. Paper 83, 1914.

Thornton, William M., Jr.
27 Titanium; with special reference to the analysis of titaniferous substances: Am. Chem. Soc., Mon. Ser., 262 pp., 1927.

Tucker, W. Burling
27 Los Angeles field division—Los Angeles County: California Min. Bur. Rept. 23, pp. 287-345, 1927.

Watson, T. L.
07 Mineral resources of Virginia, Virginia Geol. Survey, p. 300, 1907.
13 (and **Taber, S.**) Geology of the titanium and apatite deposits: Virginia Geol. Survey Bull. 111-A, 1913.

Willis, Bailey
12 (and others) Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, 1912.

Woodford, A. O.
28 (and **Harriss, T. F.**) Geology of Blackhawk Canyon, San Bernardino Mountains, California: Univ. California, Dept. Geol. Sci. Bull., vol. 17, pp. 265-304, 1928.

Bibliography

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BIBLIOGRAPHY OF THE IRON-ORE RESOURCES OF CALIFORNIA *

BIBLIOGRAPHY

Allen, Victor T.

29 The Ione formation of California: Univ. California Dept. Geol. Sci. Bull., vol. 18, pp. 347-448, 10 figs., pls. 24-37, 1929.

Ocher in Ione formation in vicinity of Knights Ferry, Stanislaus County, p. 359; Ione lateritic deposit an extension of pre-Ione laterite, p. 383. Photo showing iron deposit mapped as Ione, pl. 31b; Ione lateritic deposit considered part of Ione formation by H. W. Turner, p. 350.

Alta California, Inc.

44 Manual of war minerals of the counties of Alta (northern) California, 135 pp., Sacramento, Alta California Inc., 1944.

Compilation of information on deposits of war minerals in counties north of the Tehachapi Mountains, by County Supervisors. Occurrences of iron minerals and ore deposits listed by counties.

Arizona Mining Journal

44 Mountain Copper proceeds with Hornet operations: Arizona Min. Jour., vol. 28, no. 15, pp. 33, 34, December 30, 1944.

Aubury, Lewis E.

05 The copper resources of California: California Min. Bur. Bull. 23, 282 pp., illus., (1902) 1905.

Description of California copper mines and associated gossan deposits.

06 The structural and industrial materials of California: California Min. Bur. Bull. 38, 412 pp., illus., 1906.

Iron, pp. 297-305; list of iron-ore specimens in the Museum of the State Mining Bureau, pp. 364-365. List of mineral paint specimens in the Museum of the State Mining Bureau, pp. 368-369.

08 The copper resources of California: California Min. Bur. Bull. 50, 366 pp., illus., 1908.

Description of California copper mines and associated gossan deposits.

Averill, Charles Volney

29 San Francisco field division—Napa County: California Div. Mines and Mining, Rept. 25, pp. 213-242, illus., 1929.

Mines and mineral resources of Napa County; iron ore, p. 218. Undeveloped "deposits": (1) at head of Sulphur Creek; (2) west of St. Helena; (3) in Conn Valley.

33 The Shasta County copper belt, California, Copper Resources of the World: International Geological Congress, Washington XVI, pp. 237-240, 1933.

33a Gold deposits of the Redding and Weaverville quadrangles: California Jour. Mines and Geology, vol. 29, pp. 3-73, illus., 1933.

Mountain Copper Company deposits, pp. 38-39; production of pyrite. Geologic map of Iron Mountain region, Shasta County, showing iron ore and gossan deposits, by O. H. Hershey, pl. 1.

35 Redding field district—mines and mineral resources of Siskiyou County: California Jour. Mines and Geology, vol. 31, pp. 255-338, illus., map, 1935.

Iron, p. 330; float in sec. 10, T. 46 N., R. 10 W., M. D.

38 The Mountain Copper Company, Ltd., cyanide treatment of gossan: California Jour. Mines and Geology, vol. 34, pp. 312-330, illus., 1938.

Extraction of gold from gossan, by slime separation and cyanide treatment. Hornet pyrite mine, p. 313.

39 Redding field district—mineral resources of Shasta County: California Jour. Mines and Geology, vol. 35, pp. 108-191, illus., 1939.

Iron, pp. 159-162; Mountain Copper Company gossan and pyrite deposits, pp. 159-160, 161; possible revival of electric smelting, pp. 160-161; Jennings deposits, p. 161; Noble Electric Steel Company deposits, p. 161; Shasta Iron Company deposits, pp. 161-162.

41 Mineral resources of Humboldt County: California Jour. Mines and Geology, vol. 37, pp. 499-528, 7 figs., 1941.

* Compiled by Ellsabeth L. Egenhoff, editor, California State Division of Mines. Manuscript submitted for publication January 1947.

Black sand (beach) deposits, worked for gold content, pp. 504-505; "iron-ore occurrences" in sec. 28, T. 6 N., R. 1 E., H., p. 516.

42 Mines and mineral resources of Sierra County: California Jour. Mines and Geology, vol. 38, pp. 7-67, 17 figs., 1942.

Iron ore, pp. 48-49; Sierra Iron Company deposits, p. 49.

46 Placer mining for gold in California: California Div. Mines Bull. 135, 377 pp., 106 figs., 4 pls., 1946.

Treatment of black sand for recovery of useful minerals, pp. 77-80.

47 Mines and mineral resources of Lake County: California Jour. Mines and Geology, vol. 43, pp. 15-40, pls. 3-7, 1947.

Mineral paint, p. 22: Immel property.

Bain, H. Foster

45 A pattern for western steel production: U. S. Bur. Mines Inf. Circ. 7315, 35 pp., 4 figs., 1945.

"Describes expansion of the industry as well as the increase in population and in the consumption of steel in the West; outlines the existing favorable conditions and lists the obstacles to be overcome in the postwar period."

45a Iron and steel: California Div. Mines Bull. 130, pp. 155-165, 1945.

Steel production in California, pp. 155-160; Fontana plant, Riverside County, pp. 160-163; Vulcan deposit, San Bernardino County, pp. 161-162; Eagle Mountains deposits, Riverside County, p. 162; electric smelting, p. 164.

Baughman, Will

27 The utilization and metallurgy of titanium: California Min. Bur. Rept. 23, pp. 299-313, 1927.

Black-sand (beach) deposits, p. 310; Aptos, Santa Cruz County; Clifton (Burdick), Los Angeles County. Titaniferous iron deposits, Los Angeles County, p. 312.

Blake, William Phipps

54 On gold and platinum of Cape Blanco: Am. Jour. Sci., 2d ser., vol. 18, p. 156, 1854.

Brief comment on platinum content and grain size of Oregon and California beach sands.

58 Report of a geological reconnaissance in California: made in connection with the expedition to survey routes in California, to connect with the surveys of routes for a railroad from the Mississippi River to the Pacific Ocean, under the command of Lieut. R. S. Williamson, Corps Top. Eng'rs., in 1853, 310 pp., illus., maps, H. Balliere, New York, 1858.

Iron, pp. 14-15, 50, 210, 274, 289, 290, 303-304.

Boalich, E. S.

21 San Francisco field division—Madera County: California Min. Bur. Rept. 17, pp. 83-84, 1921.

Mines and mineral resources. Iron, Minarets deposits, p. 84.

21a Tulare County: California Min. Bur. Rept. 17, pp. 257-260, 1921.

Mines and mineral resources. Iron, p. 259.

23 Notes on iron ore occurrences in California: California Min. Bur. Rept. 18, pp. 110-113, 1923.

Brief descriptions of deposits in Butte, Calaveras, El Dorado, Los Angeles, Madera, Nevada, Placer, Plumas, Riverside, San Benito, San Bernardino, San Diego, San Luis Obispo, Shasta, Sierra, Siskiyou, and Tehama Counties.

23a San Francisco field division—San Benito County: California Min. Bur. Rept. 18, pp. 211-220, 1923.

Mines and mineral resources. Iron, p. 218 (Quilty mine).

Bradley, Walter W.

16 Napa County: California Min. Bur. Rept. 14, pp. 262-299, illus., 1916.

Mines and mineral resources. Iron deposits, p. 271: (1) at head of Sulphur Creek; (2) in Conn Valley; (3) Stirling iron mine.

16a Sonoma County: California Min. Bur. Rept. 14, pp. 316-366, illus., 1916.

Mines and mineral resources. Iron, p. 322: Hooper Ranch deposit; Lancaster Ranch yellow ocher and hematite (Fisks Mill) deposit; Fort Ross deposit. Mineral paint, pp. 333-334: Healdsburg Paint Company deposit; Meeker deposit; Occidental deposit; Sotoyome Magnesite and Mineral Paint Company.

19 (and **Logan, C. A.**) San Benito County: California Min. Bur. Rept. 15, pp. 616-673, illus., 1919.

Mines and mineral resources. Iron, p. 639; Quilty deposit.

27 The Minarets district, Madera County: California Min. Bur. Rept. 22, pp. 539-557, illus., 1927.

Review of mineral resources on which to base opposition to proposal to add Minarets district to Yosemite National Park. Iron, p. 557; Minarets deposits.

Brown, Frank E.

81 (et al.) Sierra Iron Company reports, 68 pp., San Francisco, Bacon & Company, 1881.

Brown, G. Chester

16 Kern County: California Min. Bur. Rept. 14, pp. 471-523, illus., 1916.

Mines and mineral resources. Iron, p. 516: Iron Mountain deposit; Iron Mountain Nos. 1 and 2 (Mount Breckenridge) deposits; Two to One deposit.

16a Shasta County: California Min. Bur. Rept. 14, pp. 747-809, illus., 1916.

Mines and mineral resources. Iron ore, pp. 805-806: Noble Electric Steel Company deposits, p. 805; electric smelting of ores, pp. 805-806.

16b Siskiyou County: California Min. Bur. Rept. 14, pp. 810-872, illus., 1916.

Mines and mineral resources. Iron float (sec. 10, T. 46 N., R. 10 W., M. D.), p. 865.

16c Trinity County: California Min. Bur. Rept. 14, pp. 873-925, illus., 1916.

Mines and mineral resources. Iron (secs. 4, 5, 9, 10, T. 30 N., R. 10 W., M. D.), p. 920. Mineral paint (red ocher), p. 921: Bowerman (Minersville) deposit; Southern Pacific Railroad Company deposit.

Browne, J. Ross

68 Mineral resources of the States and Territories west of the Rocky Mountains for 1868, 674 pp., 1868.

California iron-ore deposits, pp. 222-225; Chaparral Hills deposits, Butte County, p. 224; Clipper Gap deposit, pp. 223-224; Grouse Ridge deposit, Nevada County, p. 224; Ione laterite deposit, Amador County, p. 225; Santa Cruz County, p. 222; Sierra Iron Company deposits, Sierra County, pp. 222, 224; Sisters of Charity deposit, Los Angeles County, p. 224; Wades Lake deposit, Plumas County, p. 224.

Burchard, Ernest F.

13 Iron ore, pig iron, and steel: Mineral Resources U. S., 1912, pt. 1, pp. 147-202, 1913.

Eagle Mountains deposits, Riverside County, pp. 172-176.

48 Summary of the iron-ore situation in California: California Div. Mines Bull. 129, pp. 207-229, 1948.

California Miners Association

99 California mines and minerals: California Miners Assoc., [iron] pp. 277-278, 379, 394, 1899.

California Mining Journal

43 Lassen County has California's largest iron-ore deposit: California Min. Jour. vol. 13, no. 3, p. 6, 1943.

Moonlight Valley deposits, Plumas County.

California State Division of Mines

U Iron: Min. Abstracts, California Div. Mines, 52 pp., mimeographed. Not dated.

Descriptions of California iron-ore deposits, copied from Division of Mines publications.

Calkins, Frank C.

17 An occurrence of nickel ore in San Diego County, California: U. S. Geol. Survey Bull. 640, pp. 77-82 (1916), 1917.

Geology of Friday mine and vicinity.

Campbell, Donald F.

06 The iron ore of Shasta County, California: Min. and Sci. Press, vol. 93, p. 603, map, 1906.

Castello, W. O.

20 The commercial minerals of California: California Min. Bur. Bull. 87, 124, pp., 1920.

Iron, pp. 50-53: industrial application and uses; properties and ores (native iron, hematite, limonite, magnetite); distribution; tests; metallurgy. Minarets deposits, Madera County, p. 52. Pyrite, pp. 79-80.

Charles, Abbott

47 Mines and mineral resources of Stanislaus County: California Jour. Mines and Geology, vol. 43, pp. 85-100, pls. 13-15, 1947.

Mineral paint, p. 96: Voyle mine, Bartlett Ranch deposit, Weidman Ranch deposit, Ochre Mining Company's deposit.

Clark, Clifton W.

17 The geology and ore deposits of the Leona rhyolite: Univ. California, Dept. Geol. Sci. Bull., vol. 10, pp. 361-382, 1917.

Alma and Leona Heights mines, Alameda County.

Clements, Thomas

35 (and **Oakeshott, G. B.**) Lower Eocene (Martinez) of the San Gabriel Mountains, southern California (abst.): Geol. Soc. America, Proc. 1934, p. 310, 1935.

Cloudman, H. C.

19 (**Huguenin, E.**, and **Merrill, F. J. H.**) San Bernardino County: California Min. Bur. Rept. 15, pp. 775-899, illus., 1919.

Mineral resources, mines, and mining in San Bernardino County.

Iron, pp. 817-821: Cave Canyon group, p. 818; Iron Age mine, pp. 818-819; Iron Mountain, Lava Bed district, pp. 819-820; Iron Mountain, Silver Lake district, p. 820; Vulcan group, pp. 820-821.

Crawford, J. J.

94 Mines and mining products of California: California Min. Bur. Rept. 12, pp. 21-411, illus., 1894.

Iron, pp. 325-327. Amador County, p. 325: Ione Coal and Iron Company. Humboldt County, p. 326: Centerville deposit, Preston iron mine. Inyo County deposits, p. 326: (1) east slope of Argus Range; (2) head of Mountain Spring Canyon; (3) in Shepards Canyon. Los Angeles County, p. 327: Mount Gleason deposits. San Bernardino County, p. 327: West Lava Beds district (Iron Mountain deposits). Napa County, p. 327: Iron Mine Company; Conn Valley deposits. Shasta County, p. 327; Lost Confidence mine; Maxwell mine; Potter mine. Sonoma County, p. 327: Fisks Mill deposit; Fort Ross deposit; Nobles Ranch deposit.

Mineral paint, pp. 406-407. Sonoma County, pp. 406-407, Indian metallic red paint mine (hematite). Yuba County, p. 407, Motts Ranch deposit.

96 Thirteenth report (third biennial) of the State Mineralogist for the two years ending September 15, 1896: California Min. Bur. Rept. 13, 726 pp. illus., 1896.

Mines and mineral resources of California. Iron, p. 504: Del Norte County. Humboldt County, Centerville deposit. Napa County, Sulphur Creek and Conn Valley deposits. Shasta County, Lost Confidence, Maxwell, and Potter mines. Mineral paint, p. 643: Sonoma County, Indian metallic red paint mine, Paint mine, Browns ocher mine.

Creasey, S. C.

46 Geology and nickel mineralization of the Julian-Cuyamaca area, San Diego County, California: California Jour. Mines and Geology, vol. 42, pp. 15-29, 2 figs., pls. 2-4, 1946.

Geology and mining of nickel-bearing gossans at Friday mine and vicinity.

Cronise, Titus Fey

68 The natural wealth of California, 696 pp., San Francisco, H. H. Bancroft & Company, 1868.

Sierra Iron Company deposits, Sierra County, pp. 588-590.

Crossman, James H.

90 San Bernardino County: California Min. Bur. Rept. 9, pp. 214-239, 1890.

Notes on physiography, geology, mining districts, and mineral deposits of San Bernardino County. Iron, pp. 235-236: Iron Mountain deposits, Lava Bed district.

Davis, F. S.

04 Alameda County minerals: Pacific Coast Miner, vol. 9, no. 1, p. 3, January 2, 1904.

Leona Heights and Alma mines, copper.

Day, David T.

05 Black sands of the Pacific coast: 59th Cong., 1st Sess., S. Doc. 65, 24 pp., 1905.

06 (and **Richards, R. H.**) Useful minerals in the black sands of the Pacific Slope: Mineral Resources U. S., 1905, pp. 1175-1258, 1906.

Black sands as a source of gold and platinum metals. Mineral composition of black sands of California, pp. 1182-1190; smelting of iron ore from Aptos deposits, Santa Cruz County, p. 1249.

06a (and **Richards, R. H.**) Investigation of black sands from placer mines: U. S. Geol. Survey Bull. 285, pp. 150-164, 1906.

Investigation of black sand deposits as sources of gold and platinum. Table showing proportion of various minerals in California black sands, p. 152.

Dean, R. S.

37 (and **von Bernewitz, M. W.**) Smelting ores in the electric furnace: U. S. Bur. Mines Inf. Circ. 6955, 32 pp., 1937.

Iron-ore smelting, Shasta County, pp. 16-17.

DeGroot, Henry

90 The San Francisco ocean placer—the auriferous beach sands: California Min. Bur. Rept. 10, pp. 545-547, 1890.

Black beach sands in vicinity of San Francisco as source of gold; origin of gold in the sands; devices for extracting gold. Iron content of sands, p. 547.

Dehlinger, Peter

43 A magnetic survey of Sand Canyon for placer deposits, San Gabriel Mountains, California: California Inst. Technology, Div. Geol. Sci., Master's Thesis, unpub., 1943.

Diller, Joseph Silas

03 Copper deposits of the Redding region, California: U. S. Geol. Survey Bull. 213, pp. 123-132, 1903.

Gray rocks and Black Diamond deposits, Shasta County, pp. 124-125, 130, 131.

03a Iron ores of the Redding quadrangle, California: U. S. Geol. Survey Bull. 213, pp. 219-220, 1903.

Shasta County deposits: Gray Rocks and Black Diamond; Hirz Mountain, p. 220; Shasta deposits, pp. 219-220.

04 Mining and mineral resources in the Redding quadrangle, California, in 1903: U. S. Geol. Survey Bull. 225, pp. 169-179, 1904.

Shasta County deposits; p. 178: Gray Rocks and Black Diamond deposits; Hirz Mountain deposits; Shasta deposits.

06 Description of the Redding quadrangle: U. S. Geol. Survey Geol. Atlas, Redding folio (no. 138), 14 pp. 1906.

Shasta County iron-ore deposits, p. 14, areal geology sheet: Gray Rocks and Black Diamond; Hirz Mountain; Shasta.

08 Geology of the Taylorsville region, California: U. S. Geol. Survey Bull. 353, 128 pp., 11 figs., 5 pls., 1908.

Iron-ore deposits, Plumas County: Houghs Peak, p. 119; Moonlight Valley, pp. 118-119.

Donnelly, Maurice

34 Geology and mineral deposits of the Julian district, San Diego County, California: California Jour. Mines and Geology, vol. 30, pp. 331-370, 13 figs., pl. 4, 1934.

Gossan deposits in vicinity of Friday nickel mine, p. 370.

Dougherty, Ellsworth Y.

27 Magnetite deposits of Madera County, California, constitute important reserves: Eng. and Min. Jour., vol. 123, pp. 765-770, 6 figs., 1927.

Minarets deposits.

Durrell, Cordell

48 (and **Proctor, P. D.**) Iron-ore deposits near Lake Hawley and Spencer Lakes, Sierra County, California: California Div. Mines Bull. 129, pp. 165-192, 1948.

Dutton, R. E.

47 (and **Carr, M. S.**) Iron ore deposits of the western United States: U. S. Geol. Survey Strategic Minerals Inv., Prelim. Map 3-212, 1947.

Eakle, Arthur S.

14 Minerals of California: California Min. Bur. Bull. 67, 226 pp., 1914.

Descriptions of minerals found in California and list of occurrences by counties. Iron, pp. 22-23; pyrrhotite, pp. 37-38; marcasite, p. 42; pyrite, p. 43; hematite, pp. 75-76; ilmenite, pp. 76-77; magnetite, pp. 78-80; limonite, pp. 87-88; siderite, p. 95.

23 Minerals of California: California Min. Bur. Bull. 91, 328 pp., 1923.

Descriptions of minerals found in California and list of occurrences by counties. Iron, pp. 25-26; pyrrhotite, pp. 49-50; marcasite, p. 58; pyrite, pp. 58-59; hematite, pp. 100-103; ilmenite, pp. 103-104; magnetite, pp. 105-108; limonite, pp. 119-120; siderite, pp. 134-135.

Eckel, Edwin C.

14 Iron ores, their occurrence, valuation and control, 430 pp., New York, McGraw-Hill Book Company, Inc., 1914.

California iron ore, pp. 268-269, 271.

Edman, J. A.

94 Notes on the gold-bearing black sands of California: Min. and Sci. Press, vol. 69, p. 294, 1894.

07 The auriferous black sands of California: California Min. Bur. Bull. 45, pp. 5-10, appendix, pp. 11-22, illus., 1907.

Black sand (beach and river) deposits; recovery of gold and platinum therefrom. Iron minerals in sands, pp. 7-8, 10.

07a The auriferous black sands of California: Eng. and Min. Jour. vol. 83, pp. 1047-1048, 1907.

Engineering and Mining Journal

07 The utilization of black sand: Eng. and Min. Jour., vol. 83, pp. 724-725, 967, 1158-1159, 1251-1252, 1907.

Erwin, Homer D.

34 Geology and mineral resources of northeastern Madera County, California: California Jour. Mines and Geology, vol. 30, pp. 7-78, 41 figs., pl. 1, 1934.

Iron, pp. 62-65, 73, pl. 1; geology of Minarets deposits, pp. 62-65; claims on Minarets deposits, p. 73; location of deposits, pl. 1.

Fairbanks, Harold Wellman

93 Geology and mineralogy of Shasta County: California Min. Bur. Rept. 11, pp. 24-53, illus., 1893.

Iron, pp. 35, 36, 46-47; Shasta deposits, p. 36; Lost Confidence mine, p. 46.

04 U. S. Geol. Survey, Geol. Atlas, San Luis folio (no. 101), 14 pp., 2 sheets of illus., 4 maps, 1904.

Prefumo hematite deposit, San Luis Obispo County, p. 14, economic geology sheet.

Franke, Herbert A.

35 Mines and mineral resources of San Luis Obispo County: California Jour. Mines and Geology, vol. 31, pp. 402-461, illus., 1935.

Iron, Prefumo deposits, pp. 423-425; McKinney iron mines, p. 424.

Gardner, Dion L.

40 Geology of the Newberry and Ord Mountains, San Bernardino County, California: California Jour. Mines and Geology, vol. 36, pp. 257-292, figs. 1-9, pl. 2, 1940.

Iron ore, p. 261; map showing geology in vicinity of Iron Mountain (Bessemer and Alarm) deposits, Lava Bed district, scale 1″ = 4 mi. (approx.), pl. 2.

Goldstone, L. P.

90 Fresno County: California Min. Bur. Rept. 10, pp. 183-204, illus., 1890.

Mines and mineral resources (includes part of present-day Madera County). Iron, Minarets deposits (Madera County), p. 191.

Goodyear, W. A.

90 San Diego County: California Min. Bur. Rept. 9, pp. 139-154, 1890.

Mines and mineral resources. Iron ore, pp. 144, 154.

Hadley, Jarvis B.

45 Iron-ore deposits in the eastern part of the Eagle Mountains, Riverside County, California: California Div. Mines Bull. 129, pp. 1-24, figs. 1-11, pls. 1-3, 1945.

Detailed description of geology and ore deposits (North, South, Bald Eagle) in eastern Eagle Mountains. Estimate of iron-ore reserves.

Hamilton, Fletcher

22 A review of mining in California during 1921: California Min. Bur. Prelim. Rept. 8, 68 pp., 1922.

Brief notes on mining of California iron ore, pp. 19, 46-47.

Hanks, Henry G.

81 Annual report of the State Mineralogist from June 1, 1880 to December 1, 1880: California Min. Bur. Rept. 1, 43 pp., 1881.

Iron, pp. 15-16, 27-30. General discussion of ores, uses, possible production in California, pp. 27-30. Clipper Gap deposit, Placer County, p. 29. Analyses of iron-ore specimens, pp. 15-16.

82 Iron ores and iron industries of California: California Min. Bur. Rept. 2, pp. 193-201, 1882.

Production and consumption of pig-iron on Pacific Coast prior to 1882, pp. 193-195. Mountain Copper Company deposits, Shasta County, p. 195. Sierra Iron Company deposits, Sierra County, pp. 195-196. Black sand deposits, near San Francisco, p. 196. California Iron (and Steel) Company furnace, Placer County, pp. 196-200; Clipper Gap limonite deposit, p. 199. List of California iron ores in the State Museum, pp. 200-201.

84 Catalogue and description of the minerals of California as far as known, with special reference to those having an economic value: California Min. Bur. Rept. 4, pp. 61-397, illus., 1884.

Hematite, pp. 228-229; iron and iron ores, pp. 232-244; limonite, pp. 255-256; magnetite, pp. 257-259.

85 California: California Min. Bur. Rept. 5, pp. 51-127, illus., 1855.

Report on California's exhibits and participation in New Orleans World's Industrial and Cotton Centennial Exposition, 1884-85.

California iron-ore deposits: Big Trees, Calaveras County, p. 99; Clipper Gap, Placer County, pp. 99-100; Mountain Copper Company, Shasta County, pp. 100-101; Prefumo, San Luis Obispo County, p. 99; San Benito, San Benito County, p. 100; Shasta, Shasta County, pp. 99-100.

86 California minerals: California Min. Bur. Rept. 6, pt. 1, pp. 91-141, 1886.

List of minerals known to exist in California, giving localities. Hematite, pp. 113-114; limonite, p. 118; magnetite, p. 120; marcasite, p. 121; meteoric iron, p. 122; pyrrhotite, p. 128; pyrite, pp. 129-130; siderite, p. 135; titanite, p. 138.

Harder, Edmund Cecil

10 Some iron ores of western and central California: U. S. Geol. Survey Bull. 430, pp. 219-227, 1910.

California iron-ore deposits: Big Trees, Calaveras, pp. 223-225; Esmeralda, Calaveras County, pp. 223-225; Hotaling, Placer County, pp. 225-227; Iron Monarch, Calaveras County, pp. 223-224; Prefumo, San Luis Obispo County, pp. 220-223; Shasta, Shasta County, p. 219.

10a (and **Rich, J. L.**) The Iron Age iron-ore deposit near Dale, San Bernardino County, California: U. S. Geol. Survey Bull. 430, pp. 228-239, figs. 19-20, pl. 2, 1910.

Geologic investigation of Iron Age deposits.

10b Iron ores of California: Min. and Sci. Press, vol. 101, pp. 79-80, 1910.

12 Iron-ore deposits of the Eagle Mountains, California: U. S. Geol. Survey Bull. 503, 81 pp., 4 figs., 13 pls., 1912.

Detailed geologic investigation of the iron-ore deposits of the Eagle Mountains, Riverside County. Structure, character, and quantity of ores; their relation to associated rocks, including descriptions of these rocks and discussions of their relations to one another. Includes large-scale geologic maps of the ore deposits.

Harris, Lew B.

05 Register of mines and minerals, Yuba County, California: California Min. Bur., 14 pp., 1905.

Dempsey Ranch deposit, Yuba County, p. 14.

Hazzard, John C.

33 Notes on the Cambrian rocks of the eastern Mojave Desert (with a paleontological report by Colin H. Crickmay): Univ. of California, Dept. Geol. Sci. Bull., vol. 23, pp. 57-80, 1933.

Heizer, Robert F.

44 (and **Treganza, A. E.**) Mines and quarries of the Indians of California: California Jour. Mines and Geology, vol. 40, pp. 291-359, 11 figs., 1944.

Hematite and limonite, pp. 309-310, map 3.

Henshaw, P. C.
39 A Tertiary mammalian fauna from the Avawatz Mountains, San Bernardino County, California: Carnegie Inst. Washington Pub. 514, pp. 1-30, 1939.

Herres, Otto
46 Titanium—a growing industry: Mining and Metallurgy, vol. 27, no. 472, pp. 210-212, April 1946.

Hersam, Ernest A.
17 Outlook for iron and steel on the Pacific Coast: Min. and Sci. Press, vol. 115, pp. 117-122, 1917.

Hershey, Oscar H.
15 The geology of Iron Mountain: Min. and Sci. Press, vol. 111, pp. 633-638, map, 1915.
Geologic map of Iron Mountain region, scale ⅝″ = 300′. Mountain Copper Company deposits, Shasta County.

Hess, Frank L.
37 (and **Gillson, J. L.**) Titanium, in Industrial minerals and rocks (Seeley W. Mudd Memorial Series), pp. 893-910, Am. Inst. Min. Met. Eng., 1937.
Titaniferous iron deposits in Los Angeles County, p. 899.

Hewett, Donnel Foster
28 Late Tertiary trust faults in the Mohave Desert, California: Nat. Acad. Sci. Proc., vol. 14, no. 1, pp. 7-12, 1928.
36 (**Callaghan, E., Moore, B. N., Nolan, T. B., Rubey, W. W.,** and **Schaller, W. T.**) Mineral resources of the region about Boulder Dam: U. S. Geol. Survey Bull. 871, 197 pp., 14 pls., 1936.
Iron ore deposits in San Bernardino County: Cave Canyon, p. 78; Iron Age, p. 79; Iron Mountain, Silver Lake district, p. 78; Ship Mountains, p. 79; Vulcan, p. 79.
48 Iron deposits of the Kingston Range, San Bernardino County, California: California Div. Mines Bull. 129, pp. 193-206, 1948.

Hodge, Edwin T.
35 Report on available raw materials for a Pacific Coast iron industry, 5 vols., War Dept., Corps Eng., U. S. Army, Office Div. Eng., North Pacific Div., Portland, Oregon, 1935.
Descriptions of California iron-ore deposits; also dolomite, manganese, limestone, magnesite, silica (glass sand), fire clay, coal, and chromite.

Hodson, William G.
93 Shasta County: California Min. Bur. Rept. 11, pp. 395-399, 1893.
Short resume of mines and mineral resources. Iron, Shasta deposits, Gray Rocks deposits, p. 396.

Hoots, Harold W.
31 Geology of eastern part of the Santa Monica Mountains, California: U. S. Geol. Survey Prof. Paper 165, pp. 83-134, 1931.

Hornor, R. R.
18 Notes on the black sand deposits of southern Oregon and northern California: U. S. Bur. Mines Tech. Paper 196, 42 pp., 8 pls., 1918.
Black sands as a source of gold and platinum metals; as a source of iron, p. 11; Crescent City deposits, Del Norte County, pp. 33-34; mineralogical composition of the concentrates, pp. 35-37. Bibliography of reports on black sands, pp. 38-39.

Hubbard, Henry G.
43 Mines and mineral resources of Santa Cruz County: California Jour. Mines and Geology, vol. 39, pp. 11-52, 21 figs., pls. 1-2, 1943.
Aptos titaniferous beach-sand deposits, pp. 35-36, pl. 2; Triumph Steel Company plant, pp. 42-43.

Hudson, Frank S.
22 Geology of the Cuyamaca region of California with special reference to the origin of the nickeliferous pyrrhotite: Univ. California, Dept. Geol. Sci. Bull., vol. 13, pp. 175-252, pls. 9-14, 7 figs., 1 map, 1922.
Detailed geology of Friday nickel mine, pp. 212-214.

Huguenin, Emil
21 (and **Castello, W. O.**) Alameda County: California Min. Bur. Rept. 17, pp. 17-42, illus., 1921.
Mines and mineral resources. Mineral paint (Berendiere deposit), p. 28. Pyrite, pp. 32-33; Alma mine, p. 33; Leona Heights mine, p. 33.

21a (and **Castello, W. O.**) Santa Cruz County: California Min. Bur. Rept. 17, pp. 228-241, 1921.

Mines and mineral resources. Black sands, pp. 235, 236, 237: Aptos deposits, p. 236; Leonard Ranch deposits, p. 237.

Irelan, William, Jr.

88 Mineral resources of the state by counties: California Min. Bur. Rept. 8, pp. 22-691, illus., 1888.

Hematite, San Benito County, p. 490; Iron Monarch deposit, Calaveras County, p. 156; Sierra Iron Company deposits, Sierra County, p. 581; Sterling deposit, Napa County, p. 415; iron, Ventura County, p. 684.

Johnson, A. C.

48 (and **Ricker, S.**) Summary of investigations of the iron-ore deposits of California: California Div. Mines Bull. 129, pp. 231-241, 1948.

Jones, Charles Colcock

09 An iron deposit in the California desert region: Eng. and Min. Jour. vol. 87, pp. 785-788, 1909.

Vulcan deposit, San Bernardino County; also reference to Providence Mountain and Specular deposits, p. 788.

10 Iron ores of the southwest: Am. Min. Cong., 13th Ann. Session, Proc., pp. 265-273, 1910.

15 Los Angeles as an iron and steel center: Min. Oil Bull., vol. 1, no. 6, May 1915.

16 The Pacific Coast iron situation—the iron ores of California and possibilities of smelting: Am. Inst. Min. Eng. Trans., vol. 53, pp. 306-323, 1916.

Raw materials for steel industry in California. Cave Canyon deposit, San Bernardino County, p. 308; Eagle Mountains deposits, Riverside County, pp. 307-308; Vulcan deposit, San Bernardino County, pp. 308, 315-317, 318-323.

Julihn, C. E.

45 (and **Moon, L. B.**) Summary of Bureau of Mines exploration projects on deposits of raw material resources for steel production: U. S. Bur. Mines Rept. Inv. 3801, 35 pp., 1945.

Raw material for steel industry in California: chromite, iron, manganese, tungsten. Iron-ore deposits: Iron Mountain, San Bernardino County, pp. 7, 10; Iron Mountain, Silver Lake district, San Bernardino County, pp. 7-10; Mountain Copper Company deposits, Shasta County, pp. 8, 10.

Kellogg, A. E.

31 Origin of flour gold in black sands: Min. Jour. Arizona, vol. 14, no. 20, pp. 3-4, 49-50, 1931.

Kett, William F.

47 Fifty years of operation by The Mouutain Copper Company, Ltd., in Shasta County, California: California Jour. Mines and Geology, vol. 43, pp. 105-162, 3 figs., pls. 16-20, 1947.

Laizure, C. McK

21 Redding field division: California Min. Bur. Rept. 17, pp. 493-544, 1921.

Brief resume of mines and mineral resources of counties in the Redding district. Pyrite, Hornet mine, Shasta County, p. 498; iron ore, Heroult deposit, Shasta County, p. 498.

25 San Joaquin County: California Min. Bur. Rept. 21, pp. 184-200, illus., 1925.

Mines and mineral resources. Earthy red hematite at Ladd manganese mine, p. 191.

25a Stanislaus County: California Min. Bur. Rept. 21, pp. 200-222, illus., 1925.

Mines and mineral resources. Foliated hematite occurrence near La Grange, p. 208. Mineral paint, pp. 213-214: California Ochre Mining Company, p. 213; Weidman Ranch deposit, p. 214; Voyle mine, p. 214.

25b Del Norte County: California Min. Bur. Rept. 21, pp. 281-294, 1925.

Mines and mineral resources. Black-sand deposits worked for gold and platinum content, pp. 284-285; iron (black sand and hematite) occurrences, p. 293.

25c Humboldt County: California Min. Bur. Rept. 21, pp. 295-324, illus., 1925.
Black sand (beach and river) deposits, worked for gold and platinum content, pp. 300-301. Iron (hematite and magnetite) deposits, pp. 317-318; Centerville deposit, pp. 317-318; Preston property, p. 318.
25d San Luis Obispo County: California Min. Bur. Rept. 21, pp. 499-538, illus., 1925.
Mines and mineral resources. Iron, Prefumo deposit, pp. 501, 515-522; McKinney iron mines, pp. 518-522.
26 San Francisco field division—Santa Cruz County: California Min. Bur. Rept. 22, pp. 68-93, illus., 1926.
Mines and mineral resources. Titaniferous black sand deposits, Aptos, pp. 70-71, 74-75, 82-84; Triumph Steel Company plant, pp. 82-84.
26a San Francisco field division—San Benito County: California Min. Bur. Rept. 22, pp. 217-247, illus., 1926.
Mines and mineral resources. Iron ore, Quilty deposit, p. 236; gossan deposit, Antelope copper mine, p. 236.
26b Sonoma County: California Min. Bur. Rept. 22, pp. 327-365, illus., 1926.
Mines and mineral resources. Iron, p. 335: Hooper Ranch deposit; Lancaster Ranch ocher deposit; Fort Ross deposit. Mineral paint, pp. 338-339: Healdsburg Paint Company ocher deposit, Meeker ocher deposit, Occidental ocher deposit, Mark West Springs ocher deposit.
28 San Francisco field division—Mariposa County: California Div. Mines Rept. 24, pp. 72-153, illus., 1922.
Mines and mineral resources. Iron ore, p. 123.
28a San Francisco field division—Madera County: California Div. Mines and Mining, Rept. 24, pp. 317-345, illus., 1928.
Mines and mineral resources. Iron, pp. 336-337, 341-343: Mount Raymond deposits (Vulcan Copper Company, Hart iron deposit), pp. 336-337; Minarets deposits (Noble Electric Steel Company), pp. 341-343.
29 San Francisco field division—Alameda County: California Div. Mines Rept. 25, pp. 427-456, illus., 1929.
Mines and mineral resources. Mineral paint, p. 437: McLean red shale (Berendiere) deposit. Pyrite, pp. 439-441: Alma mine (Stauffer Chemical Company), p. 440; Leona Heights mine (Leona Chemical Company), pp. 440-441.

Lamey, Carl A.

45 Iron Mountain iron-ore deposits, Lava Bed district, San Bernardino County, California: California Div. Mines Bull. 129, pp. 25-38, figs. 12-15, pl. 4, 1945.
45a Iron Mountain and Iron King iron-ore deposits, Silver Lake district, San Bernardino County, California: California Div. Mines Bull. 129, pp. 39-58, figs. 16-18, pls. 5-7, 1945.
45b Old Dad Mountain iron-ore deposit, San Bernardino County, California: California Div. Mines Bull. 129, pp. 59-67, figs. 20-22, 1945.
45c Cave Canyon iron-ore deposits, San Bernardino County, California: California Div. Mines Bull. 129, pp. 69-83, figs. 23-29, pl. 8, 1945.
45d Vulcan iron-ore deposit, San Bernardino County, California: California Div. Mines Bull. 129, pp. 85-95, figs. 30-33, pl. 9, 1945.
45e Iron Hat (Ironclad) iron-ore deposits, San Bernardino County, California: California Div. Mines Bull. 129, pp. 97-109, figs. 34-37, pl. 10, 1945.
45f Ship Mountains iron-ore deposit, San Bernardino County, California: California Div. Mines Bull. 129, pp. 111-116, fig. 38, pls. 11-12, 1945.
45g Hirz Mountain iron-ore deposits, Shasta County, California: California Div. Mines Bull. 129, pp. 129-136, fig. 44, pls. 14-16, 1945.
45h Shasta and California iron-ore deposits, Shasta County, California: California Div. Mines Bull. 129, pp. 137-164, figs. 45-53, pls. 17-19, 1946.

Lang, Herbert

16 Black sand of the Pacific coast: Min. and Sci. Press, vol. 113, pp. 811-813, 1916.

Lawson, Andrew Cowper

14 U. S. Geol. Survey Geol. Atlas, San Francisco folio (no. 193), 24 pp., 1 sheet illus., 15 maps, 1914.
Leona Heights and Alma pyrite mines, Alameda County, Concord areal geology sheet, p. 22.

Leith, C. K.

06 Iron ores of the western United States and British Columbia: U. S. Geol. Survey Bull. 285, pp. 194-200, 1906.

Cave Canyon deposit, San Bernardino County, p. 198.

Lindgren, Waldemar

94 U. S. Geol. Survey Geol. Atlas, Sacramento folio (no. 5), 3 pp., 4 maps, 1894.

Hotaling deposit, Placer County, p. 3, economic geology sheet.

95 (and **Turner, H. W.**) U. S. Geol. Survey Geol. Atlas, Smartsville folio (no. 18), 6 pp., 4 maps, 1895.

Newton and Nickerson Ranch deposits, Nevada County, p. 6, economic geology sheet.

28 Mineral deposits, 3d ed., New York, McGraw-Hill Book Co., Inc., 1928.

Shasta deposits, Shasta County, p. 804.

Logan, Clarence A.

19 San Luis Obispo County: California Min. Bur. Rept. 15, pp. 674-726, illus., 1919.

Prefumo deposit, San Luis Obispo County, pp. 688-689.

19a Platinum and allied metals in California: California Min. Bur. Bull. 85, 120 pp., illus., 1919.

Analyses of black sand (beach and river) deposits, p. 43.

21 Placer County: California Min. Bur. Rept. 17, pp. 441-454, illus., 1921.

Mines and mineral resources. Hotaling deposit, pp. 452-453.

25 Sacramento field division—Calaveras County: California Min. Bur. Rept. 21, pp. 135-172, illus., 1925.

Mines and mineral resources. Iron ore, p. 162: Big Trees deposit, Esmeralda deposit, Iron Monarch deposit.

25a Sacramento field division—Siskiyou County: California Min. Bur. Rept. 21, pp. 414-498, illus., 1925.

Mines and mineral resources. Iron, p. 491.

26 Sacramento field division—Shasta County: California Min. Bur. Rept. 22, pp. 121-216, illus., 1926.

Mines and mineral resources. Iron ore deposits: Deep Pit, p. 192; Gray Rocks, p. 190; Hirz Mountain, p. 190; Mountain Copper Company gossan and pyrite deposits, pp. 142, 154-160; Shasta, pp. 190-192.

Includes *Copper*, by W. B. Tucker, pp. 138-162.

26a Sacramento field division—El Dorado County: California Min. Bur. Rept. 22, pp. 397-452, illus., 1926.

Iron, p. 441: Chaix, Gutenberger Ranch, Reliance, Simons Ranch deposits.

27 Sacramento field division—Amador County: California Min. Bur. Rept. 23, pp. 131-202, illus., 1927.

Mines and mineral resources. Iron deposits: Clinton, p. 199; Ione lateritic, p. 199.

27a Sacramento field division—Placer County: California Min. Bur. Rept. 23, pp. 235-286, illus., 1927.

Mines and mineral resources. Iron deposits, p. 281: Hotaling; Weimer.

28 Sacramento field division—Butte County: California Div. Mines and Mining, Rept. 24, pp. 173-210, illus., 1928.

Mines and mineral resources. Iron-ore deposits, p. 207: Diamond Match, Mineral Slide, Remple.

29 Sacramento field division—Sierra County: California Div. Mines and Mining, Rept. 25, pp. 151-212, maps, 1929.

Mines and mineral resources. Sierra Iron Company iron deposits, pp. 211-212.

30 Sacramento field division—Butte County: California Div. Mines Rept. 26, pp. 360-412, illus., 1930.

Mines and mineral resources. Iron-ore deposits, p. 407; Diamond Match, Mineral Slide, Remple.

43 Current mining activity in Plumas County: California Jour. Mines and Geology, vol. 39, pp. 85-87, 1943.

Iron, Hungry Creek deposits, pp. 86-87.

Lowell, F. L.

16 The counties of Del Norte, Humboldt, Mendocino: California Min. Bur. Rept. 14, pp. 371-425, illus., 1916.

Mines and mineral resources. Del Norte County: black sands worked for gold and platinum-metals content, pp. 375-379. Humboldt County: black sand (beach and river deposits), worked for gold content, p. 391; iron (hematite) "deposits," p. 408; vivianite occurrences, p. 408; ocher "deposits," p. 414.

Lyon, David A.

14 The electric furnace in pig-iron manufacture: U. S. Bur. Mines Bull. 67, pp. 7-57, 1914.

California, pp. 31-57: Cave Canyon deposit, San Bernardino County, p. 40; Iron Mountain deposits, Silver Lake district, San Bernardino County, p. 40; Minarets deposits, Madera County, p. 40; Shasta deposits, Shasta County, p. 41; Vulcan deposit, San Bernardino County, p. 40.

MacBoyle, Errol

19 Mines and mineral resources of Nevada County: California Min. Bur. Rept. 16, pt. 1, 270 pp. illus., 1919.

Indian Springs gossan deposit, pp. 262-263.

20 Mines and mineral resources of Plumas County: California Min. Bur. Rept. 16, pt. 2, 188 pp. illus., 1920.

Moonlight Valley iron-ore deposit, p. 36.

Mace, Clement H.

11 Genesis of Leona Heights ore deposit, California: Min. and Eng. World, vol. 35, p. 1320, 1911.

McGregor, Alex

90 Shasta County: California Min. Bur. Rept. 10, pp. 627-641, 1890.

Shasta iron-ore deposits, p. 641.

Merrill, Frederick J. H.

16 San Diego County: California Min. Bur. Rept. 14, pp. 637-722, illus., 1916.

Juch iron-ore deposit, p. 668; gossan at Friday mine.

19 Los Angeles County: California Min. Bur. Rept. 15, pp. 465-514, illus., 1919.

Mines and mineral resources. Iron (titaniferous), p. 478: Russ Siding deposit; Iron Mack deposit.

19a Riverside County: California Min. Bur. Rept. 15, pp. 522-589, illus., 1919.

Mines and mineral resources. Iron, pp. 544-545: Eagle Mountains deposits (hematite, some magnetite).

Miller, William J.

34 Geology of the western San Gabriel Mountains of California: Univ. California, Los Angeles, Pub. Math. and Phys. Sci., vol. 1, pp. 1-114, 1934.

Titaniferous iron-ore deposits, p. 22.

44 Geology of Palm Springs—Blythe strip, Riverside County, California: California Jour. Mines and Geology, vol. 40, pp. 11-72, 23 figs., pls. 1-4, 1944.

Iron ore in Eagle Mountains, Riverside County, pp. 31-32.

Mining and Scientific Press

84 Iron in California: Min and Sci. Press, vol. 48, p. 192, 1884.

08 Iron ore deposits in Shasta County, California: Min. and Sci. Press, vol. 97, p. 667, 1908.

Moorhouse, W. W.

38 Some titaniferous magnetites of the San Gabriel Mountains, Los Angeles County, California: Econ. Geology, vol. 33, pp. 737-748, 1938.

Newberry, J. S.

61 Geological report, in Report upon the Colorado River of the west: U. S. 36th Cong., 1st sess., H. Doc. 14, no. 90, pt. 3, 154 pp., illus., maps, 1861.

Iron, Purple Hills, Imperial County, p. 21; San Diego County, p. 151.

Newhouse, W. H.

36 (and **Glass, J. P.**) Some physical properties of certain iron oxides: Econ. Geology, vol. 31, pp. 699-711, 3 figs., 1936.

Maghemite in Alameda County. Shasta deposits, Shasta County.

Nolan, T. B.

43 The Basin and Range province in Utah, Nevada and California: U. S. Geol. Survey Prof. Paper 197-D, 1943.

Iron, San Bernardino County, p. 148.

O'Brien, J. C.

43 Current notes on activity in the strategic minerals, Redding field district: California Jour. Mines and Geology, vol. 39, pp. 77-84, 1943.

Iron-ore deposits: Lantz, Lassen County, p. 79; Shasta deposits, Shasta County, p. 82.

43a Current notes on the activity in the strategic minerals, Redding field district: California Jour. Mines and Geology, vol. 39, pp. 323-330, 1943.

Shasta iron-ore deposits, Shasta County, p. 327.

Oakeshott, Gordon B.

36 A detailed geologic section across the western San Gabriel Mountains of California: Univ. Southern California, Ph.D. Thesis, unpub., 1936.

37 Geology and mineral deposits of the western San Gabriel Mountains, Los Angeles County: California Jour. Mines and Geology, vol. 33, pp. 215-249, 7 figs., pl. 3, 1937.

Geology of southern Lang, northern Sunland, and Tujunga quadrangles. Titaniferous iron-ore deposits in Los Angeles County, pp. 248, 312.

48 Titaniferous iron-ore deposits of the western San Gabriel Mountains, Los Angeles County, California: California Div. Mines Bull. 129, pp. 243-266, 1948.

Pabst, Adolf

38 Minerals of California: California Div. Mines Bull. 113, 344 pp., 1938.

Descriptions of minerals found in California and list of occurrences by counties. Iron, pp. 34-35; pyrrhotite, pp. 62-63; pyrite, pp. 71-72; marcasite, p. 73; hematite, pp. 108-111; ilmenite, pp. 111-112; magnetite, pp. 114-117; limonite, pp. 129-131; siderite, p. 144.

Phelps, R. L.

07 The electrical smelting of iron ore: Min. and Sci. Press, vol. 95, pp. 87-89, 1907.

Shasta iron-ore deposits, Shasta County.

Pierce, H.

41 War's effect on iron ore: Min. Cong. Jour., vol. 27, no. 2, pp. 28-29, February 1941.

Popert, William H.

45 Steel; California Monthly, pp. 8-10, 42, 44, April 1945. . . . California Jour. Mines and Geology, vol. 41, pp. 93-96, pls. 15-22, 1945.

Prescott, Basil

08 The occurrence and genesis of the magnetite ores of Shasta County, California: Econ. Geology vol. 3, pp. 465-480, figs. 39-41, 1908.

Shasta deposits, Shasta County.

Putnam, Bayard T.

86 Notes on the samples of iron ore collected west of the one-hundredth meridian: U. S. Census Rept. 10, vol. 15, pp. 469-505, figs. 216-224, 1886.

California iron ore, pp. 493-496, 503-504.

Ramsay, George D.

44 The Fontana steel plant and its raw material supply: Min. and Metallurgy vol. 25, no. 453, pp. 423-426, 1944.

Vulcan deposit, San Bernardino Connty.

Raymond, Rossiter W.

70 Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1870, 805 pp., 1870.

Iron-ore deposits: Big Trees, Calaveras County, p. 29; Sierra Iron Company, Sierra County, p. 59; Wades Lake, Plumas County, p. 59.

73 Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1873, 550 pp., illus., 1873.

Iron-ore deposits: Sierra Iron Company, Sierra County, p. 91; Wades Lake, Plumas County, p. 91.

74 Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1874, 585 pp., 1874.

Iron-ore deposits: Sierra Iron Company, Sierra County, pp. 43-47, 138; Wades Lake, Plumas County, pp. 43-47.

Richthofen, F., Baron von

65 (Sierra Iron Company), Virginia City, Nevada, November 1865.

Ricker, Spangler

45 War-time mineral industry of California: California Jour. Mines and Geology, vol. 41, pp. 37-44, 1945.

Sampson, Reid J.

37 Mineral resources of Los Angeles County: California Jour. Mines and Geology, vol. 33, pp. 173-213, illus., 1937.

Mines and mineral resources; includes *Petroleum*, by Emil Huguenin, pp. 209-213. Titaniferous iron deposits, pp. 196, 197, 213.

42 (and **Tucker, W. B.**) Mineral resources of Imperial County: California Jour. Mines and Geology, vol. 38, pp. 105-145, 11 figs., 1 pl., 1942.
Iron-ore, Churchill deposit, p. 126, pl. 1.

Sanford, Samuel
14 (and **Stone, R. W.**) Useful minerals of the United States: U. S. Geol. Survey Bull. 585, California pp. 24-38, 1914.
Iron minerals in California, pp. 25-26, 31, 32, 34, 35, 37, 43.

Schrader, Frank C.
17 (**Stone, R. W.**, and **Sanford, S.**) Useful minerals of the United States: U. S. Geol. Survey Bull. 624, 412 pp., 1917.
California, pp. 42-80: brown ore, pp. 45-46; iron ore, p. 61; hematite, p. 60; ilmenite, p. 61; magnetite, pp. 64-65; marcasite, p. 66; ocher, p. 67; pyrite, p. 70; pyrrhotite, p. 71; siderite, p. 74.

Severy, C. L.
46 Exploration of the Minarets iron deposit, Madera County, California: U. S. Bur. Mines Rept. Inv. 3985, 12 pp., 8 figs., 1946.
Report on diamond-drilling program of U. S. Bureau of Mines, and metallurgy of ore.

Singewald, Joseph T., Jr.
13 The titaniferous iron ores in the United States, their composition and economic value: U. S. Bur. Mines Bull. 64, 145 pp., 3 figs., 16 pls., 1913.

Smith, James Perrin
14 The middle Triassic marine invertebrate faunas of North America: U. S. Geol. Survey, Prof. Paper 83, 254 pp., illus., 1914.

Sperisen, Francis J.
38 Gem minerals of California: California Div. Mines Rept. 34, pp. 34-78, 1938.
Iron, pp. 43-44.

Storms, W. H.
93 San Bernardino County: California Min. Bur. Rept. 11, pp. 337-369, illus., 1893.
Iron Mountain iron-ore deposits, Lava Bed District, San Bernardino County, p. 349.

Thompson, David G.
29 The Mohave Desert region, California: U. S. Geol. Survey Water-Supply Paper 578, 759 pp., 1929.
Iron-ore deposits in San Bernardino County: Cave Canyon, pp. 32, 509; Iron Age, p. 32; Iron Hat, pp. 32, 691; Iron Mountain, Lava Bed District, p. 631; Iron Mountain, Silver Lake district, pp. 32, 596; Vulcan, pp. 32, 679.

Tolman, C. F., Jr.
16 (and **Rogers, A. F.**) A study of the magmatic sulfid ores, 76 pp., 20 pls., 7 figs., Leland Stanford Jr. Univ. Pubs., Univ. Ser., 1916.
Ores at Friday mine, San Diego County, pp. 39-41.

Trask, Parker Davies
45 (and **Simons, F. S.**) Minarets magnetite deposits of Iron Mountain, Madera County, California: California Div. Mines Bull. 129, pp. 117-128, figs. 39-43, pl. 13, 1945.

Tucker, W. Burling
16 Amador County: California Min. Bur. Rept. 14, pp. 3-53, illus., 1916.
Mineral resources and mines. Iron, p. 52: Ione deposit; Clinton deposit.
16a Calaveras County: California Min. Bur. Rept. 14, pp. 54-131, illus., 1916.
Mineral resources and mines. Iron, p. 128: Big Trees limonite deposit.
19 Tulare County: California Min. Bur. Rept. 15, pp. 900-954, illus., 1919.
Mines and mineral resources. Iron, pp. 917-918: Franklin Canyon (pyrrhotite) deposit, p. 917; Lady Emma deposit, pp. 917-918.
21 Inyo County: California Min. Bur. Rept. 17, pp. 273-305, illus., 1921.
Mines and mineral resources. Iron, p. 282: Roper deposit, Coso deposit.
21a Kern County: California Min. Bur. Rept. 17, pp. 306-316, illus., 1921.
Mines and mineral resources. Iron, p. 312: Mount Breckenridge deposit, San Emidio deposit, Iron Mountain (secs. 10, 15, T. 26 S., R. 29 E., M. D.) deposit.
21b Riverside County: California Min. Bur. Rept. 17, pp. 324-332, illus., 1921.
Mines and mineral resources. Iron, p. 327: Eagle Mountains deposits.

23 Redding field division: California Min. Bur. Rept. 18, pp. 595-601, 1923.
Brief review of current mining activity in Lassen, Shasta, Siskiyou, Trinity Counties.
Iron, Shasta County: pp. 598, 600; Deep Pit gossan deposit, p. 598; Shasta iron mine, p. 600.

23a Redding field district: California Min. Bur. Rept. 18, pp. 729-736. illus., 1923.
Brief resume of current mining activity in Shasta, Siskiyou, Trinity Counties.
Iron, Shasta County, p. 732: Shasta iron mine.

23b Redding field division—review of mining during 1922: California Min. Bur. Rept. 19, pp. 7-13, 1923.
Iron ore (magnetite), p. 12: Heroult deposit, Shasta County. Pyrite, mined for sulphur content, p. 12: Hornet mine, Shasta County.

24 Los Angeles field division: California Min. Bur. Rept. 20, pp. 33-50, illus., 1924.
Short resume of mining in Imperial, Inyo, Kern, Los Angeles, Orange, Riverside, San Bernardino, San Diego Counties.
Iron, Los Angeles County, p. 43: Pacific Coke & Coal Company, plans for erection of furnace near Long Beach. Vulcan deposit, San Bernardino County, p. 43.

24a Los Angeles field division: California Min. Bur. Rept. 20, pp. 185-200, illus., 1924.
Resume of mineral resources and mines of Inyo, Kern, Riverside, San Bernardino Counties.
Iron, Riverside County, p. 196; Iron Chief (Eagle Mountains) mine.

24b Los Angeles field division: California Min. Bur. Rept. 20, pp. 367-374, 1924.
Short resume of mining activity in Kern, San Bernardino, San Diego Counties.
Iron, San Diego County, p. 374: Iron Master (magnetite), Lakeview (hematite, magnetite) claims.

25 Los Angeles field division—San Diego County: California Min. Bur. Rept. 21, pp. 325-382, illus., 1925.
Mines and mining. Iron, pp. 349-350; Friday mine (gossan), p. 349; Iron Master claims, p. 350; Lakeview claims, p. 350; Campo deposit, p. 350.

26 Copper: California Min. Bur. Rept. 22, pp. 138-162, 1926.
Iron Mountain mine, Shasta County, p. 142.

26a Los Angeles field division—Imperial County: California Min. Bur. Rept. 22, pp. 248-285, illus., 1926.
Mines and mineral resources. Iron, p. 262: Churchill deposit; mineral paint, pp. 277-278.

26b Los Angeles field division—Inyo County: California Min. Bur. Rept. 22, pp. 453-530, illus., 1926.
Mines and mineral resources. Iron, pp. 474-475: Coso deposit, LeCyr deposit, Roper deposit.

27 Los Angeles field division—Los Angeles County: California Min. Bur. Rept. 23, pp. 287-345, illus., 1927.
Mines and mineral resources. Iron (titaniferous), pp. 295-313: Mill Creek deposits—Baughman claims, Iron Mountain group, Mammoth group, Bryant group, pp. 296-297; Iron Blossom group, p. 297; Iron Mack mine, p. 297; Needham and Boruff claims, p. 298; Russ Siding deposit, p. 298; Titian group, p. 298; Burdick Minerals Corporation (beach-sand deposits), pp. 298-299, 310; Titanium Corporation plant, p. 299; *The utilization and metallurgy of titanium*, by Will Baughman, pp. 299-313; value of titaniferous ores, p. 313.

29 Los Angeles field division—Kern County: California Div. Mines and Mining, Rept. 25, pp. 20-81, illus., 1929.
Mines and mineral deposits. Iron, pp. 56-57: Iron Mountain deposit, p. 56; Mount Breckenridge deposit, p. 56; San Emidio deposit, p. 57.

29a (and **Sampson, R. J.**) Los Angeles field division—Riverside County: California Div. Mines Rept. 25, pp. 468-526, illus., 1929.
Mines and mineral resources. Iron, pp. 489-491: Iron Chief (Eagle Mountains) mine.

30 (and **Sampson, R. J.**) Los Angeles field division—San Bernardino County: California Div. Mines Rept. 26, pp. 202-325, illus., 1930.
Mines and mineral resources. Iron, pp. 260-264: Cave Canyon deposit, p. 261; Iron Age deposit, p. 261; Iron Hat (Ironclad) deposit, pp. 261-262; Iron Mountain deposits, Lava Bed district, p. 262; Iron Mountain deposits, Silver Lake district, p. 262; Kingston Mountains deposit, p. 262; Ship Mountains iron mine, pp. 263-264; Vulcan deposit, p. 264.

31 (and **Sampson, R. J.**) Los Angeles field division—San Bernardino County: California Div. Mines Rept. 27, pp. 262-401, illus., 1931.

Mines and mineral resources. Iron, pp. 333-337: Cave Canyon deposit, pp. 333-334; Iron Age deposit, p. 334; Iron Hat (Ironclad), p. 334; Iron Mountain, Lava Bed district, p. 335; Iron Mountain, Silver Lake district, p. 335; Kingston Mountains, p. 335; Ship Mountains, pp. 335-336; Vulcan deposit, pp. 336-337. Map showing locations of deposits.

38 Mineral development and mining activity in southern California during the year 1937: California Jour. Mines and Geology, vol. 34, pp. 8-19, 1938.

Mining activity in Imperial, Inyo, Kern, Los Angeles, Mono, Riverside, and San Bernardino Counties briefly reviewed.

Iron, pp. 17-18: Hoot Owl deposit, Inyo County, p. 17; titaniferous iron deposits, Los Angeles County, pp. 17-18.

38a (and **Sampson, R. J.**) Mineral resources of Inyo County: California Jour. Mines and Geology, vol. 34, pp. 368-500, illus., 1938.

Mines and mineral resources; map showing locations of principal mines.

Iron, pp. 424-425: Coso deposit, Hoot Owl deposit, LeCyr deposit, Roper deposit.

39 (and **Reed, C. H.**) Mineral resources of San Diego County: California Jour. Mines and Geology, vol. 35, pp. 8-55, illus., 1939.

Iron, p. 29: Iron Master claim; Lakeview claims; Companion No. 1 mine.

40 (and **Sampson, R. J.**) Current mining activity in southern California: California Jour. Mines and Geology, vol. 36, pp. 9-82, 1940.

Iron, San Bernardino County, p. 68.

40a (and **Sampson, R. J.**) Economic mineral deposits of the Newberry and Ord Mountains, San Bernardino County: California Jour. Mines and Geology, vol. 36, pp. 232-254, illus., 1940.

Iron, p. 241: Iron Mountain deposits, Lava Bed district.

43 (and **Sampson, R. J.**) Current notes on activity in the strategic minerals, Los Angeles field district: California Jour. Mines and Geology, vol. 39, pp. 58-70, 1943.

Resume of mining activity in Inyo, Kern, Mono, Riverside, San Bernardino, and San Diego Counties.

Iron, San Bernardino County, pp. 66-67: Bessemer and Western iron mines (Iron Mountain mine; California Iron Company), in secs. 27, 28, T. 6 N., R. 4 E., S. B.

43a (and **Sampson, R. J.**) Current mining activity in southern California: California Jour. Mines and Geology, vol. 39, pp. 118-138, 2 figs., 1943.

Resume of mining activity in Imperial, Inyo, Kern, Orange, Riverside, San Bernardino Counties.

Iron, San Bernardino County: Black Jack mine, p. 127; Vulcan mine, pp. 135-136; iron and steel plant of Kaiser Company, Inc., at Fontana, p. 137.

43b (and **Sampson, R. J.**) Mineral resources of San Bernardino County: California Jour. Mines and Geology, vol. 39, pp. 427-549, 27 figs., pls. 5-7, 1943.

Iron, pp. 465-473; Bessemer and Western (Iron Mountain) mines, Lava Bed district, p. 467; Black Jack deposit, p. 468; Cave Canyon deposit, p. 468; Cave Mountain deposit, p. 469; Copper World deposit, p. 469; Dorris May (Eaton gold mine) deposit, p. 469; Globerson mine, p. 469; Iron Age deposit, pp. 469-470; Iron Hat deposit, p. 470; Iron Mountain deposit, Silver Lake district, p. 470; Kingston Mountain deposit, pp. 470-471; Nigger Head deposit, p. 471; Ship Mountain deposit, p. 471; Van Buren group, pp. 471, 473; Vulcan mine, p. 473. Includes county map showing locations of mines.

45 (and **Sampson, R. J.**) Mineral resources of Riverside County: California Jour. Mines and Geology, vol. 41, pp. 121-182, 1 fig., pls. 23-35, 1945.

Iron, pp. 145-146. Iron Chief mine, pp. 145-146; Iron Cap (Maria Mountains) deposit, p. 146; Palen Mountain deposit, p. 146.

46 Current notes: California Jour. Mines and Geology, vol. 42, p. 319, 1946.

Millspaugh iron deposit, Inyo County; Tiefort Mountains iron deposit, San Bernardino County.

Turner, Henry Ward

94 U. S. Geol. Survey Geol. Atlas, Jackson folio (no. 11), 6 pp., 4 maps, 1894.

Iron-ore deposits, p. 6, economic geology sheet: Clinton and Ione lateritic, Amador County; Esmeralda and Iron Monarch, Calaveras County.

97 U. S. Geol. Survey Geol. Atlas, Downieville folio (no. 27), 8 pp., 1 sheet illus., 4 maps, 1897.

Iron-ore deposits, p. 8, economic geology sheet: Sierra Iron Company, Sierra County; Wades Lake, Plumas County.

98 (and **Ransome, F. L.**) U. S. Geol. Survey Geol. Atlas, Big Trees folio (no. 51), 8 pp., 1 sheet illus., 3 maps, 1898.

Big Trees iron-ore deposit, Calaveras County, p. 8, economic geology sheet.

Tyssowski, John

10 Electric smelting of iron ore at Heroult, Cal.: Eng. and Min. Jour., vol. 90, pp. 269-271, 1910.

Shasta deposits, Shasta County.

U. S. Bureau of Mines

43 Eagle Mountains iron district, Riverside County, Calif.: U. S. Bur. Mines War Minerals Rept. 97, 44 pp., 8 figs., 1943.

Exploration of eastern part of the Eagle Mountains iron district; estimate of ore reserves; investigation into beneficiation of representative types of ore, and study of conditions bearing upon their exploitation.

43a Shasta Iron Company property, Shasta County, Calif.: U. S. Bur. Mines, War Minerals Rept. 124, 4 pp., 1943.

Analysis and estimate of iron-ore reserves.

45 Iron Mountain deposits, San Bernardino County, Calif.: U. S. Bur. Mines War Minerals Rept. 418, 8 pp., 2 figs., 1945.

Iron-ore reserves at Iron Mountain, Silver Lake district, estimated on basis of drilling by Bureau of Mines.

45a Shasta and California iron ore deposits, Shasta County, California: U. S. Bur. Mines, War Minerals Rept. 465, 12 pp., 2 figs., 1945.

45b Effect of the war upon the mineral industry of California: U. S. Bur. Mines, War Minerals Rept. 469, 19 pp., 1945.

U. S. Geological Survey

06 Survey publications on iron and manganese: U. S. Geol. Survey Bull. 285, pp. 201-202, 1906.

Bibliography of principal papers on iron and manganese ores published by the U. S. Geological Survey or by members of its staff.

07 Survey publications on iron and magnanese ores: U. S. Geol. Survey Bull. 315, pp. 213-214, 1907.

Bibliography of principal papers on iron and manganese ores published by the U. S. Geological Survey or by members of its staff.

Waring, Clarence A.

19 (and **Huguenin, E.**) Inyo County: California Min. Bur. Rept. 15, pp. 29-134, illus., map, 1919.

Mines and mineral resources. Iron, p. 87: Roper deposit, Coso deposit.

19a Placer County: California Min. Bur. Rept. 15, pp. 309-399, illus., 1919.

Mines and mineral resources. Hotaling iron-ore deposit, p. 390.

Watts, W. L.

90 Merced County: California Min. Bur. Rept. 10, pp. 323-331, 1890.

Mines and mineral resources. Iron, p. 331.

93 Fresno County: California Min. Bur. Rept. 11, pp. 210-218, illus., 1893.

Mines and mineral resources of Fresno County (including part of present-day Madera County). Minarets iron-ore deposit, p. 214.

93a Humboldt County: California Min. Bur. Rept. 11, pp. 227-232, 1893.

Mines and mineral resources. Black sand, pp. 228, 232.

93b Marin County: California Min. Bur. Rept. 11, pp. 249-254, 1893.

Mines and mineral resources. Maillard Ranch iron deposit, p. 253.

93c Sonoma County: California Min. Bur. Rept. 11, pp. 453-463, 1890.

Mineral resources. Iron, pp. 461-462; deposits in vicinity of Fort Ross, p. 461; Fisks Mill deposit, p. 462; ocher.

93d Tulare County: California Min. Bur. Rept. 11, pp. 485-492, 1893.

Mines and mineral resources. Iron, p. 492.

Weeks, F. B.

16 The Minaret iron deposit: California Min. Bur. Rept. 14, pp. 555-558, 2 figs., 1916.

Wells, Francis G.

46 (**Cater, F. W. Jr.**, and **Rynearson, G. A.**) Chromite deposits of Del Norte County, California: California Div. Mines Bull. 134, pt. 1, pp. 1-76, 9 figs., 11 pls., 1946.

Crescent City beach sands, pp. 75-76.

Whitney, Josiah Dwight

65 Geology of California. Geology, vol. 1, report of progress and synopsis of the field-work from 1860 to 1864, 474 pp. 1865.

Iron-ore deposits: Big Trees, Calaveras County, pp. 259-260; Cañada de las Uvas, Los Angeles County, pp. 189, 194; Clipper Gap, Placer County, p. 284; Ione lateritic, Amador County, p. 270; Mountain Copper Company, Shasta County, p. 322.

Wiese, John H.

46 (and **Page, L. R.**) Tin deposits of the Gorman district, Kern County, California: California Jour. Mines and Geology, vol. 42, pp. 31-52, 4 figs., pls. 5-7, 1946.

Geology of tin-bearing iron deposits (gossan and magnetite) in southern Kern County.

Williams, Clyde E.

21 Factors in the production of iron and steel on the Pacific Coast: Min. and Sci. Press, vol. 123, pp. 94-96, 1921.

Willis, Bailey

12 Index to the stratigraphy of North America: U. S. Geol. Survey, Prof. Paper 71, 894 pp., map, 1912.

Woodford, Alfred Oswald

28 (and **Harriss, T. F.**) Geology of Blackhawk Canyon, San Bernardino Mountains, California: Univ. California, Dept. Geol. Sci. Bull., vol. 17, pp. 265-304, 1928.

Wright, Randall

37 Magnetic iron sulphide of Pliocene of Ventura Basin, California: Am. Assoc. Petroleum Geologists Bull. 21, pp. 627-630, 1937.

Youngman, E. P.

30 Deposits of titanium-bearing ores: U. S. Bur. Mines Inf. Circ. 6386, 41 pp., 1930.

California deposits, pp. 3-5: Aptos, Santa Cruz County; Burdick Minerals Corporation, Russ Siding, Mount Gleason, Los Angeles County.

INDEX TO BIBLIOGRAPHY

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Camp Meeker ocher deposit, Sonoma County: See Meeker ocher deposit.

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Cañada de las Uvas deposit, Los Angeles County: Putnam, B. T. 86, p. 503; Whitney, J. D. 65, pp. 189, 194.

Castaic deposits, Kern County: See Lake Castaic deposits.

Cave Canyon deposits (sec. 12, T. 11 N., R. 6 E., S. B.), San Bernardino County: Aubury, L. E. 06, p. 299; Boalich, E. S. 23, p. 112; Cloudman, H. C. 19, p. 818; Hewett, D. F. 36, p. 78; Hodge, E. T. 35, v. 1, pp. d, 44; v. 3, ap. E-5, p. 14; Jones, C. C. 16, p. 308; Lamey, C. A. 45c; Leith, C. K. 06, p. 198; Lyon, D. A. 14, p. 40; Thompson, D. G. 29, pp. 32, 509; Tucker, W. B. 30, p. 261; 31, pp. 333-334; 43b, p. 468.

Cave Mountain deposit (sec. 20, T. 12 N., R. 6 E., S. B.), San Bernardino County: Tucker, W. B. 43b, p. 469.

Centerville deposit (sec. 2?, T. 1 N., R. 3 W., sec. 35?, T. 2 N., R. 3 W., H.) Humboldt County: Crawford, J. J. 94, p. 326; 96, p. 504; Laizure, C. McK 25c, pp. 317-318.

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Chaparral Hill(s) deposits, Butte County: Browne, J. R. 68, p. 224; Putnam, B. T. 86, p. 504.

Churchill deposit (sec. 33, T. 9 S., R. 16 E., M. D.), Imperial County: Sampson, R. J. 42, p. 126, pl. 1; Tucker, W. B. 26a, p. 262.

Clinton deposit (sec. 8, T. 6 N., R. 12 E., M. D.), Amador County: Logan, C. A. 27, p. 199; Tucker, W. B. 16, p. 52; Turner, H. W. 94, p. 6, economic geology sheet.

Clipper Gap deposits, Placer County: Browne, J. R. 68, pp. 223-224; Hanks, H. G. 82, p. 199; 84, pp. 234, 237-239, 255; 85, pp. 99, 100; Hodge, E. T. 35, v. 1, p. 39; v. 3, ap. E-5, p. 9; Putnam, B. T. 86, pp. 494-495, 504; Whitney, J. D. 65, p. 284; see also Hotaling deposit.

Coast Metals and Reduction Company: See Aptos titaniferous beach-sand deposits, Santa Cruz County.

Companion No. 1 deposit, San Diego County: Tucker, W. B. 39, p. 29; see also Campo deposit.

Complex deposits, Shasta County: See Iron Mountain deposits.

Condor titaniferous deposit, Los Angeles County: Tucker, W. B. 27, p. 297; see also Baughman, Mill Creek titaniferous deposits.

Conn Valley deposit, Napa County: Averill, C. V. 29, p. 218; Bradley, W. W. 16, p. 271; Crawford, J. J. 94, p. 327; 96, p. 504.

Copper World deposit (sec. 22?, T. 2 N., R. 11 E., S. B.), San Bernardino County: Tucker, W. B. 43b, p. 469.

Cornfield deposit, San Bernardino County: Hodge, E. T. 35, v. 1, p. 40; v. 3, ap. E-5, p. 10.

Coso deposit (secs. 9, 10, 11, 14, 15, 16, T. 20 S., R. 39 E., M. D.), Inyo County: Tucker, W. B. 21, p. 282; 26b, p. 475; 38a, p. 425; Waring, C. A. 19, p. 87.

Crescent City black-sand deposits (approx. sec. 19, T. 16 N., R. 1 W., H.), Del Norte County: Hornor, R. R. 18, pp. 33-34.

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Daytonia titaniferous deposits, Los Angeles County: Tucker, W. B. 27, p. 297; see also Baughman, Mill Creek titaniferous deposits.

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———, black-sand deposits of: Hornor, R. R. 18, pp. 33-34; Laizure, C. McK 25b, pp. 284-285, 293; Lowell, F. L. 16, pp. 375-379; Wells, F. G. 46, pp. 75-76.

———, iron-ore deposits in: Crawford, J. J. 96, p. 504; Laizure, C. McK 25b, p. 293.

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Detert deposit (sec. 11, T. 4 N., R. 10 E., M. D.), Calaveras County: Aubury, L. E. 06, p. 297; see also Iron Monarch deposit.

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Devils Punch Bowl deposit (sec. 1, T. 16 N., R. 4 E., H.), Siskiyou County: Hodge, E. T. 35, v. 5, pt. 1, p. 72.

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Dorris May deposit (sec. 19, T. 1 S., R. 13 E., S. B.), San Bernardino County: Tucker, W. B. 43b, p. 469.

Dunton deposit, Kern County: See Lake Castaic deposits.

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———, iron-ore deposits in: Aubury, L. E. 06, p. 297; Boalich, E. S. 23, p. 110.

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———, of ore from Shasta deposits: Brown, G. C. 16a, pp. 751, 805-806; Dean, R. S. 37, pp. 16-17; Tyssowski, J. 10.

———, possible revival of: Averill, C. V. 39, pp. 160-161.

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Fisks Mill deposit (T. 9 N., R. 13 W., M. D.), Sonoma County: Aubury, L. E. 06, p. 304; Boalich, E. S. 23, p. 112; Bradley, W. W. 16a, p. 322; Crawford, J. J. 94, p. 327; Watts, W. L. 93c, p. 462; see also Lancaster Ranch ocher deposit.

Fontana plant, Riverside County: Bain, H. F. 45a, pp. 160-163; Ramsay, G. D. 44; Tucker, W. B. 43a, p. 137.

Fort Ross deposit(s) (T. 8 N., R. 12 W., M. D.), Sonoma County: Aubury, L. E. 06, p. 304; Boalich, E. S. 23, p. 112; Bradley, W. W. 16a, p. 322; Crawford, J. J. 94, p. 327; Laizure, C. McK 26b, p. 335; Watts, W. L. 93c, p. 461.

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Friday gossan and pyrrhotite deposits (sec. 15, T. 13 S., R. 4 W., S. B.), San Diego County: Calkins, F. C. 17; Creasey, S. C. 46; Donnelly, M. 34, p. 370; Hudson, F. S. 22, pp. 212-214; Merrill, F. J. H. 16, p. 668; Tolman, C. F., Jr. 16, pp. 39-41; Tucker, W. B. 25, p. 349.

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